STUDIES ON INTEGRATED NUTRIENT MANAGEMENT WITH SPECIAL REFERENCE TO BIOFERTILIZERS

A

Thesis Submitted for the Degree of

DOCTOR OF PHILOSOPHY

University of Allahabad

By

Ved Prakash Yadav

M.Sc. (Ag. Chem. & Soil Science)

Sheila Dhar Institute of Soil Science

UNIVERSITY OF ALLAHABAD

ALLAHABD

December 2002

Enrolment No. 97AU/2566

Dedicated

To My

Venerable Parents

SHEILA DHAR INSTITUTE OF SOIL SCIENCE

University of Allahabad

(Established in 1935)

5-Lajpat Rai Road
Allahabad-211002

Dr. Dinesh Mani, D.Sc.
Senior Lecturer

Ref. No. .... **Dated** 21.12.2002

CERTIFICATE

This is to certify that Sri Ved Prakash Yadav has conducted research work under my supervision on the topic entitled "Studies on Integrated Nutrient Management with Special Reference to Biofertilizers" for the award of the degree of Doctor of Philosophy in Science, of the Allahabad University. To the best of my knowledge, the data presented in the thesis are genuine and original.

Dinesh Mani

December 2002 **(DINESH MANI)**

Allahabad

ACKNOWLEDGEMENT

I am highly indebted to my guide Dr. Dinesh Muni, Senior Lecturer, Sheila Dhar Institute of Soil Science, University of Allahabad for taking his keen intrest, valuable suggestions, constructive criticism and everlasting zeal which he showed in solving several intricate problems during the course of present study and successful completion of this manuscript to its final form. It would have never been possible for me to complete the work and prepare the thesis without his sympathetic and helpful attitude.

I also express my deep sense of gratitude and thanks to Prof. M.M. Verma, Ex-Director, Sheila Dhar Institute of Soil Science, Ex-head, Department of Chemistry, University of Allahabad, for his encouragement and valuable suggestions during the completion of the thesis work.

I am also grateful to Dr. Arvind Singh, Dr. R.S. Yadav, Dr. S.N. Singh, Mr. P.C. Yadav and all my friends and well wishers specially Dr. K.K. Tripathi, Arun Prakash, Dhritanjai, Chitranjan, Sanjay, Krishna Kumar, Harishchandra, Man Mohan Lal, who helped during the entire course of my research work.

I am highly indebted to my venerable father Sri Jansi Yadav, mother Smt. Gyanwati Yadav, uncle Sri B.D. Yadav, brothers, sisters and other family members for their kind help, affection, inspiration, co-operation and moral support throughout my study period to reach this destiny cheerfully.

A grateful acknowledgement is also due to the University of Allahabad for providing me Sheila Dhar Memorial Fellowship during the period of research work.

My grateful thanks to the staff members of Sheila Dhar Institute of Soil Science, Allahabad who helped me for time to time. My grateful thanks to staff and officials of Vivekanand Parvatiya Krishi Anusandhan Sansthan, Almora for providing me the laboratory facilities for Soil and Plant Analysis.

Lastly, I also thank to Mr. Ajay Kesarwani and Dhiraj (Aparna Computer Point, Katra, Allahabad) for typing this manuscript.

December, 2002

Allahabad

Ved Prakash Yadav 21.XII.02

(Ved Prakash Yadav)

Abbreviations

FYM	=	Farm Yard Manure
AAS	=	Atomic absorption spectrophotometer
pH	=	Potential of hydrogen ion
NPK	=	Nitrogen, phosphorus, potassium
t	=	tonnes
ha	=	hectare
kg	=	Kilogram
DAS	=	Days after sowing
OC	=	Organic carbon
EC	=	Electrical conductivity
CD	=	Critical Difference
SE	=	Standard error
NS	=	Non significant
LTFE	=	Long term fertilizer experiment
ppm	=	parts per million
DTPA	=	Diethlene triamine penta-acetic acid

CONTENTS

Chapter		Page No.
I	Introduction	1 - 12
II	Review of literature	13 - 36
III	Materials and Methods	37 - 47
IV	Results and Discussion	48 - 114
V	Summary and Conclusion	115 - 123
	Bibliography	124 - 139

Chapter I

Introduction

Chapter-I

INTRODUCTION

Maximization of food grain production per unit of arable land is our national priority. Enhanced and sustained yields have to be harnessed from rainfed, dry and barren lands through intelligent management of renewable native soil and water resources and accelerated use of inputs like chemical fertilizers. The post-green revolution period has been characterized by enhanced use of chemical fertilizers with share of organic progressively declining. The net result has been the appearance of multinutri~~ent~~al deficiencies, declining and unsustainable yields of different crop rotations and scares of environmental contamination. Although chemical fertilizers have been linked with soil and water pollution, their application rates in India are much below the world average and the same could easily be doubled. However, enhanced use of chemical fertilizers shall have to be supplemented with matching addition of organic matter. Harnessing benefits by favorably manipulating the soil organisms inducing them to fix more atmospheric N_2 and solubilize unavailable P and micronutrients will be a bonus accruing from an ideal Integrated Plant Nutrient System (IPNS). Exploitation of synergistic and minimization of antagonistic interactions will further catalyze the enhanced production of food-grains. Another novel approach of evolving and growing crop cultivars capable of mining immobile nutrients like P, Fe, Zn and Cu from soil reserves will provide higher yields, thus avoiding the use of these nutrients as fertilizers. Any viable IPNS has to aim at obtaining desired sustained yield goals with economically rational use of chemical fertilizers supplemented with environmentally acceptable doses of organic using more biofertilizers,

growing nutrient-efficient crop cultivars (capable of mobilizing native soil nutrients) and adopting appropriate use of crop residues wherever and whenever available. Soil scientists, plant nutritionists, agronomists, plant breeders and other concerned scientists would be increasingly called upon to undertake interdisciplinary work to solve the complex problems of integrated soil, nutrient and water management leading to enhanced productivity, sustainability, profitability and equity.

In a densely populated country like India with a long history of civilization, man has been exploiting the reserves of nutrients in soil from time immemorial. In 1951-52, the food-grain production was merely 52 Mt with fertilizer consumption of only 70 thousand tonnes, whereas the food-grain production has increased to an all time high of 206 Mt during 1999-2000 with fertilizer consumption of about 18 Mt to feed a billion. For the present level of production the estimated NPK removal is about 28 Mt resulting a net negative balance of about 10 Mt. Organic manures and bio-fertilizers contribute about 4 Mt, which means that about 6 Mt negative balance has to be replenished by soil. This is a serious soil health hazard, which needs urgent attention of all concerned. Recently, the Government of India has announced the target of doubling of food production within 10 years. It implies that for doubling the productivity, the nutrient removal would be more than double of the present level to about 56 Mt, since nutrition requirement for the incremental production would be higher. The gap between nutrient supply through all sources and removal would further escalate to more than 12 Mt from the present level (1999-2000) of about 6 Mt, provided the contribution of organic and biofertilizer sources is also doubled. Thus the soil health problem would further aggravate.

The integrated nutrient management would be essential and

inevitable in view of the fact that to produce 300 Mt of food-grains, 30-35 million tonnes of N + P_2O_5 + K_2O will be needed by 2025 and for commercial crops 14-15 million tonnes NPK will be needed. Thus, from both inorganic and organic sources the country will be required to arrange for the supply of about 40-45 million tonnes of nutrients by the years 2025.

India's highest policymaking body, the Planning Commission has projected annual food-grain requirement (targets) at 337 Mt by 2011-2012 (final year of the 11^{th} 5-Year Plan). Indian agricultural policies, inspite of their aberrations and inconsistencies have always depended on planning for adequate, sometimes exaggerated, amounts of fertilizer to meet agricultural production targets. Currently available estimates are for 30 Mt of $N+P_2O_5+K_2O$ by 2006-2007 and 45.5 Mt by 2011-2012. If one examines the past trends in the growth of fertilizer consumption, then the targets will require massive all round efforts in production, import, distribution and application to be translated into reality. Fertilizer consumption increased by 3.1 Mt during 1970s, by 5.9 Mt during 1980s and by 7.1 Mt during 1990s. The Planning Commission target of 45 Mt in fact translated to a 2.5 times the present level of consumption. Will fertilizer use increase by 27mt in 12 years (2000-2012)?

It is apparent that N removal can reach 328 kg N/ha/year in rice-wheat-green gram rotation, P removal can reach 150 kg P_2O_5/ha/year. K removal goes up to 389 kg K_2O/ha/year in (rice-wheat-cowpea fodder) and annual NPK uptake of 438 to 814 kg/ha under high intensity cropping (i.e., two to three crops/year). Production of 8 to 12t grain/ha is associated with N uptake of 139 to 328 kg/ha, P uptake of 70 to 120 kg P_2O_5/ha and K uptake of 202 to 389 kg K_2O/ha. These figures serve as a guideline for fertilizer recommendation.

In primitive agriculture, plants derive nutrients from the native soil reserves. Before the advent of the era of "Green Revolution", besides soil sources, accretion of nutrients occurred from organic manures and inadvertently from incorporation of crop residues including stubble. Larger removal of nutrients by high yielding varieties progressively impoverished the soils of their native nutrient reserves. Appearances of the deficiencies of N, P, K, Zn, S and subsequently multinutrients at the same time in that sequence reflected the sickness of soil; calling for immediate correction of the problem. Deficiencies of secondary and micronutrients such as S and Zn were further accentuated by the use of high analysis fertilizers such as diammonium phosphate. This is, thus, linked to the concept of integrated plant nutrient system.

According to Roy and Ange (1991), the basic concept underlying IPNS is the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. IPNS is an approach ecologically, socially and economically viable and environmentally unhazardous, at the same time sustaining soil productivity through optimization of all possible sources, both organic and inorganic. In India, unfortunately, the current thinking is that only supplementation with farmyard manure constituents a viable IPNS sending wrong signals worldwide prompting a member country of EEC even to make a preposterous suggestion to export cattle dung to India.

The basic concept of the integrated plant nutrition system (IPNS) is the maintenance of soil fertility and plant nutrient supply at the optimum level for sustaining crop productivity using all possible sources of plant nutrients in an integrated manner. The integration of

various sources of plant nutrients has become imperative because of escalating prices. The appropriate integration of the various sources of plant nutrients, inorganic fertilizers and organic manures, for example farmyard manure (FYM), compost, green manure (crop residues) and N-fixing microbes, varies according to the system of land use and ecological, social and economic conditions. Farmers, based on their experience, have understood the beneficial effect of organic manures on crops and soils and to a limited extent have followed plant nutrient management systems.

The supply of organic sources of nutrients, e.g. FYM and compost, for field application depends on the number of animals a farmer possesses and how much dung can be spared for the preparation of FYM after meeting the domestic requirement for fuel. In India it is estimated that only 4-5 months of the dung supply is available for field application. Thus until alternative sources of energy are available for growing a green manure crop. The concept of IPNS, based on local resource utilization, needs to be demonstrated on the farmer's field in order to be adopted. It is important that the application of organics should not be constructed as a substitute for inorganic sources of plant nutrients, but should be viewed as a supplement to inorganic sources. Research in Asia on various sources of nutrients such as chemical fertilizer, biofertilizer, compost and industrial wastes, green manure and bio-gas, etc., have demonstrated beneficial effects of integrated plant nutrient management on crop yields and for maintaining soil fertility. The practice has resulted in increased efficiency of fertilizer use and economies on total cost.

The objective of nutrient management strategies is to achieve the required crop yield in an efficient, economical and sustainable manner through removal of constraints including nutrient deficiencies. A major constraint to sustainability in India is poor soil

fertility. Although fertilizer use has been increasing rapidly in India over the years but there is a stagnation of crop production. This seems to be due largely to the incorrect use of fertilizers. Farmers have been applying relatively higher amounts of nitrogen, but only small quantities of phosphate. Other fertilizers, such as potash and micronutrients are hardly used at all. Organic sources are not being properly integrated with mineral fertilizers. Under such conditions, the soil is depleted and it takes more nitrogen every season to obtain the same crop. Declining crop responses to fertilizer are inevitable if the application of nutrients is depleted and it takes more nitrogen every season to obtain the same crop. Declining crop responses to fertilizer are inevitable if the application of nutrients is repeatedly unbalanced and does not correspond to the needs of the soil and the crops grown upon it. A crop's overall demand and the amount removed from the soil must be replaced sooner or later if soil fertility levels are to be maintained. Unless the plant nutrients removed by the harvested crops and otherwise lost to the ecosystem are replaced, the agricultural production system cannot be sustainable in the short or long term. If the nutrients are replaced, intensive agricultural system can be sustained indefinitely. If conversely, plant nutrient deficits are not replaced in some way, no agricultural system can be sustained, at least in the long term. In the world as a whole but especially in the developing countries like India, year after year, far more nutrients are being mined from soils than are being replaced.

Roy and Ange (1991) summarized that the IPNS, having optimum combination of mineral fertilizers, organic manures, crop residues, compost or N-fixing crops, offer the following attractions:

- Organic/biological sources of plant nutrients complement mineral fertilizers in meeting nutrient requirements of crops; the magnitude of contribution will vary according to sources and

agro-ecological conditions.

- In many situations, synergistic effects due to combined application could be expected, thus increasing the fertilizer use efficiency.
- Residual effects of added organic sources in the cropping system could also be expected together with an improvement in physical conditions.
- Under high input production systems, where plant productivity cannot be further increased with incremental use of mineral fertilizers alone, addition of organic sources could again increase the yields through increased soil productivity and fertilizer use efficiency.

The Food and Agriculture Organization (FAO) has evolved a concept of 'Integrated Plant Nutrition Systems' (IPNS) which aims at the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner (Roy and Ange 1991). The basic principle of IPNS is the maintenance of soil fertility, sustainable agricultural productivity and improving farmers' profitability through the judicious and efficient use of mineral fertilizers, organic matter, green manure, biological N_2 fixation and other inoculants. Thus balanced fertilization strategy evolved on the sound principles of IPNS is a viable means of evolving the sustainable agriculture.

The main objective of the integrated nutrient management (INM) is to efficiently utilize all the sources of plant nutrients viz., soil nutrients, chemical fertilizers, organic manures and crop residues, green manures, biologically fixed N_2 and biofertilizers. Each of these

sources is separately discussed below:

Investigations on different crops receiving labeled fertilizers have conclusively demonstrated that a major portion of the nutrient uptake comes from soil. On the national level, the soil depletion of nutrients ($N + P_2O_5 + K_2O$) over the years has remained steady at 8-10 million tonnes per annum. Particularly alarming is the huge negative balances of K in spite of its application to some extent. If this imbalance is not immediately corrected, then K-hungry soils would irreversibly consume tonnes of K without crops responding to its application. Larger doses of P needed on high-P fixing soils, is yet another example. Over- exploitation of zinc reserves under heavy zinc consuming cropping systems expressed itself in large scale occurrences of its deficiencies. Thus the important task of integrated nutrient management is the efficient management of soil nutrients. The loss of soil nutrients can be greatly reduced through effective soil and water conservation measures and appropriate crop rotations. The enhancement of crop uptake through the right package of practices for growing crop also reduces the possibility of loss of nutrients by various mechanisms. The supply of plant nutrients from the soil can be enhanced through the so-called priming effect. It is known that the application of organic manures triggers the microbial activity and results in increased mineralization of soil nutrition.

Green revolution coincided with the transformation of "soil dependent agriculture" into a "fertilizer-dependent one". However, use efficiency of fertilizers in India continues to be very low, resulting in a colossal wastage of financial resources. For example, fertilizer N use efficiency seldom exceeds 40 percent under lowlands and 60 per cent under upland conditions, in best managed package of practices, the efficiencies of P and Zn fertilizers hardly exceed 20 and 2 per cent, respectively. Unutilized fertilizer N has a potential of contaminating

atmosphere with N_2O and polluting ground waters with nitrates; excessive P application has been linked with heavy metal (viz. Cd, Pb) accretion to the soil. Maximization of fertilizer use efficiency tops the agenda on fertilizer research in developing Asia, as highlighted by Ange (1992). He concluded that by forging high efficiency of fertilizer with associated innovations, saving of 70 kg/ha ($N + P_2O_5 + K_2O$) by 2010 and 95 kg/ha in 2030 AD could be effected. von Uexkull and Mutert (1992) recommended that the nutrient supplementation through chemical fertilizer must be balanced through five considerations. (i) nutrient need of the current crop and removal through the harvest, (ii) nutrient loss through erosion, volatilization, leaching, fixation, etc., (iii) available nutrient status, (iv) accretion of nutrients from air, irrigation water, through crop residues, farmyard manure and compost, and (v) amount of N added through biological N fixation.

The fertilizer consumption increased tremendously during the last few decades. No doubt, there has been a close relationship between the fertilizer consumption and production however; the intensive cropping through the cultivation of HYV and multiple cropping resulted in heavy nutrient removal bringing about serious imbalances in soil fertility. Heavy fertilizers inputs created a great strain on the fertilizer industry. Because of heavy agricultural production on one hand the soil demands a continuous replenishment of essential nutrients, on the other hand, the energy crisis prohibits a heavy inputs of fertilizers. Under the circumstances, a judicious use of chemical fertilizer, organic and bio-fertilizer seems to be a viable alternative. The present trust on the search and application of bio-fertilizer in agriculture is a present day need.

Biofertilizers enhance soil fertility and yield of crops by rendering unavailable sources of elemental nitrogen, bond phosphates

and decomposed plant residues into available forms in order to facilitate the plants to absorb the nutrients. In recent years due emphasis has been paid to chemical nitrogenous and phosphatic fertilizers. (Tilak, 1995).

Biological N-fixation is estimated to contribute about 140×10^6 metric tonnes of nitrogen annually (Burns and Hardy, 1975), eight percent of which comes from symbiotic associations and the remaining from free living systems. The enzyme nitrogenase, responsible for conversion of dinitrogen to ammonia, is restricted to certain prokaryotic organisms.

Nitrogen fixation by rhizobium in root nodules of legumes is of the order of 14 million tonnes on a global scale and is, almost half that of the industrial N-fixation which has been estimated to be 30 million tonnes per year. It is now known that the yield of pulses and oil seed crops can be stopped up substantially by the use of rhizobial cultures as shown by the extensive studies in different parts of the country under the All India Coordinated Pulses, Oilseeds, Legumes and Soybean Improvement Research Programmes (Rewari, 1988, a, b; Balasundaram, 1988; Kulkarni et al. 1984). Some of the results, from rhizobium inoculation trials, with Chickpea (Cicer arietinum), Mung bean (Vigna radiata), Urd bean (Vigna mungo), Pigeonpea (Cajanus cajan), Lentil (Lens esculenta) and Cowpea (Vigna unguiculata) were obtained. The result show that the percent increase in crop yield due to rhizobium inoculation varied from 8.5- 54.0, 22.9- 84.8, 13.0- 19.6, and 13.5- 21.9 and15.3- 23.0 over un-inoculated controls, respectively.

India is endowed with enormous potential for plant nutrients locked up in biological and industrial by-products. The total annual nutrient ($N + P_2O_5 + K_2O$) potential of these so-called waste materials is of the order of 19.11 Mt, out of which cattle dung manure alone

accounts for 6.88 million tonnes. Von Uexkull and Mutert (1992) summarized the supplying essential nutrients in balanced ratio through relatively slow release and stimulating soil flora and fauna and organic manures. These factors improved the soil physical environment by way of (i) improving soil structure, water holding capacity and soil aeration, (ii) moderating soil surface temperature and (iii) reducing soil losses due to erosion.

Organic manures play a vital role in the maintenance of soil fertility. With the introduction of HYV, the need of nutrients per unit land, particularly of NPK, has substantially increased. Chemical fertilizers are commonly used for supply of major elements, whereas organics supply macro and micro elements and humus substances particularly humic and fulvic acids. Organic manure also promote root growth, retain plant nutrients because of high CEC and act as slow release fertilizer thereby ensure availability of nutrients on long term basis. The residual effect of organic manure is known to improve properties of the soil.

Incorporation of green manures with legume shrubs or tree lopping for sustaining soil health has been an age-old practice. However expansion of agriculture associated with enhanced cropping intensities and excellent response of miracle varieties to chemically fixed nutrients, primarily pushed this practice to the background. Catastrophic effects became visible soon in the form of declined crop productivity and deteriorated soil health. Improvement in soil physical environment in terms of reduced bulk density and enhanced hydraulic conductivity was the beneficial effect associated with straw incorporation. Crop residues mulch were beneficial for soil and water conservation, regulating soil moisture and temperature regimes, improving soil structure, enhancing activity of soil fauna, suppressing weed growth and protecting soil from high intensity rains and from

desiccation.

The objectives of the present research work undertaken in this thesis are as follows:

1. To study the effect of rhizobium, phosphorus/NPK fertilizers and FYM on growth attributes and nutrient contents in plants.

2. To study the effect of rhizobium, phosphorus/NPK fertilizers and FYM on physicochemical properties of soil.

Chapter II

Review of Literature

Chapter-II

REVIEW OF LITERATURE

The present study emphasizes on the effect of INMS on green gram (Vigna radiata L) and lentil (Lens esculenta L). In view of the objectives, the available literature has been reviewed as follows:-

Singh (1999) observed the continuous application of NPK/NPK+FYM which increased the status of organic C in alluvial soils to the tune of 27-52%, 50-90% in medium black soils, 45-77% in red loam soils and 174% in lateritic soils. Application of NPK+ lime of FYM increased the number, dry weight and volume of nodules on the roots of soybean in acid red loam soils.

Results emanating from the LTFEs in India revealed that the application of 100% NPK in combination with farmyard manure reduced the bulk density and increased the water stable aggregates percentage and hydraulic conductivity after 7-11 years of manuring (Nambiar & Ghosh 1984). In a 68 year study, at Aizu, Fukushima, Japan, balanced application of NPK (70 kg N + 90 kg P_2O_5 + 90 kg K_2O per hectare), NPK + 12 t FYM/ ha, NPK + 6 t rice straw/ha and NPK + FYM + amendment (1500 kg calcium silicate + 450 kg magnesium phosphate/ha) improved the supply of readily available water; combination of organic matter and mineral fertilizers improved porosity, thereby, substantially reducing the bulk density of soils (Von Uexkull & Mutert 1992). Sarkar et al. (1989) reported that the supplementation of entire N through farmyard manure for 28 years reduced the bulk density and improved the water holding capacity on an acid red loam soil of Ranchi; balanced application of lime and NPK had a moderately favorable effect on water holding capacity. Prasad (1994) reported that the application of chemical fertilizers alone on

calcareous soils of Pusa, Bihar did not improve much the physical environment of soil; highest soil macro-aggregation (> 1 mm) and micro-aggregation (0.3 – 1.0 mm) was observed in the treatment of 100% NPK + 10 t FYM/ha + 13 kg BGA/ha or 100% NPK + 10 Mg FYM/ha. Thus different studies indicate that the supplementation of NPK along with organics sustains favourable soils physical environment.

Nambiar and Ghosh (1984) summarized that in the LTFEs, organic carbon increased appreciably under 100% NPK + FYM treatments in all the cases and significantly in some of the soils; organic carbon build-up over the years (1971-82) under NPK + FYM application was 27 to 52% in alluvial, 50 to 92% in medium black, 45 to 77% in red loam and 174% in laterite soils. In intensively cultivated rice-based cropping systems practiced at Barrackpore and Pantnagar. Depletion of organic carbon occurred to the tune of 0.03-0.08% and 0.32-0.80% after 12-13 years of crop cycles (Patnaik et al. 1989). Bhardwaj and Omanwar (1994), however, observed that on tarai soils whereas continuous cropping without fertilization depleted the soil of its native soil organic matter (SOM) and available N, P, K, Fe, Mn, Zn and Cu status. Integrated use of chemical fertilizers and FYM enhanced the SOM, available N, P and K status of the soil. They further stressed that the average depletion of 0.899, 1.057, 0.171 and 0.079 kg/ha of available Fe, Mn, Cu and Zn respectively, after 9th cycle of cropping was an alarming situation for sustainability of rice-wheat-cowpea (fodder) cropping system.

On almost all the soils under LTFEs, the available soil-N improved appreciably over the initial levels after 17 years of intensive cropping at optimal (100% NPK) and super-optimal levels (150% NPK) of chemical fertilizers (Nambiar 1994); on alluvial soil of Delhi, application of 100% NPK for seven years raised the contents of amino

acid, hydrolysable-NH_4^+, hexosamine and total hydrolyzable N significantly, thereby enriching the soil organic-N pool. Increase in available N status under continuous fertilizer-N supply was also confirmed from the results of permanent manurial trial at Ranchi (Sarkar et al. 1989).

Ghosh (1987) contended that since a bulk of the applied P remained unutilized by the crop, a positive balance and a commensurate rise in soil test P provided adequate support in favour of its residual and cumulative effect. Nambiar (1994) reported that the available soil P in optimal (100% NPK) and super-optimal (150% NPK) NPK doses appreciated from low to high on Chromustert (Jabalpur); medium to high on Ustochrept (Delhi), Haplustalf (Ranchi) and Hapludoll (Pantnagar); high to very high on Eutrochrept (Barrackpore), and Hapludalf (Palampur); and low to very high on Ustochrept (Ludhiana). According to Sarkar et al. (1989), continuous fertilization of red loam soil with P for 28 years in combination with other nutrients and amendments enhanced the available P from initial 7.5-ppm to 72.5-220.0 ppm.

Nambiar (1994) reported an appreciable build-up of available soil K an optimal (100%) NPK on Ustochrepts (Delhi and Ludhiana) and Haplustalf (Ranchi), and at super-optimal (150%) NPK rate on Hapludalf (Palampur) and Hapludoll (Pantnagar); considerable soil mining of available K occurred over the years on Vertic Ustochrept (Coimbatore), Chromustert (Jabalpur) and Tropaquept (Hyderabad), where decline in available K occurred even under the super-optimal treatment. Ghosh (1987) summarized that NPK crop removal of K was mostly heavy, which was further accelerated in multiple cropping with high yielding strains, whereas its external supplementation was much less. Kemmler (1987) has already warned that if larger negative balance of K was not taken care of then soil K might turn into a

serious yield-limiting factor.

Large-scale occurrence of zinc deficiency, particularly in wetland rice, appears to be fallout of "Green Revolution" with nearly 50% of more than 1.50 lakh samples being deficient in available zinc. LTFE data indicate that the crops started responding to zinc application on an Ustochrept of Ludhiana and Hapludollof Pantnagar after a decade of continuous cropping under optimum NPK dose (Nambiar & Abrol 1989). Nambiar (1994) reported that application of zinc to soils raised the level of available Zn considerably; incorporation of FYM along with NPK not only sustained the initial level but also enhanced it in all the soils with the sole exception of the Vertic Ustochrept of Coimbatore where the available zinc content declined. Availability of other micronutrients, *viz.* Fe, Mn and Cu has been quite satisfactory even after nearly two decades of cropping. Fragility of integrated nutrient management of rice-wheat cropping system of highly percolating light textured soils has manifested itself in terms of large-scale occurrence of Mn deficiencies in Punjab (Takkar & Nayyar 1981). This clearly elucidated that the INM systems developed have to be continuously monitored and modified, if necessary, to combat the new technology-induced problems.

Nodules are the niche of microorganisms specially Rhizobium bacterial where they live and fix atmospheric nitrogen. biofertilizer significantly increase number of nodules, nodule dry weight and leghaemoglobin content of nodules. But the effect is not similar on each crop and variety. A significant interaction is found between genotypes and strains. Raut and Goniskar (1983) from Parbhani reported that Rhizobium inoculation is pigeonpea brought significant improvement in nodule number and its dry weight. The nitrogen accumulation increased by 37 percent over control. Rasal et al. (1998) reported significant increase in number of nodules in urd

bean due to inoculation. An increase in number of nodules due to inoculation in urd bean has also been reported (Kemi et al. 1991 and Sarkar et al. 1998).

Amongst single and multi strain inoculants of Rhizobium, the highest number of nodule and its dry weight in chickpea cv. BDN-9-3 were obtained with G-13; a single strain inoculant at Badanapur, Maharashtra. An increase of 73 to 92 percent was observed in number of nodules in chickpea plants with Rhizobial inoculation over uninoculated (control) under Gujarat conditions. Patel et al. (1986) observed the beneficial effects of inoculation with biofertilizers (Rhizobium/VAM) in mung bean have been reported by several Rajmash, (French bean) is very poor nodulating crop. Consequently, heavy dose of N (120 kg N/ha) has to be applied to realize its yield potential. Rai (1992) reported significant interaction between Rhizobium strains (USDA 2689, 2674 and ND5) and cultivars (PDR 14, HUR 15 and HUR 138) which resulted in more nodulation and greater nitrogen activity in normal soil with 12.5 mg nitrogen/kg soil. He also observed that strain (ND 1 and ND 2) produced greater nodulation and nitrogenase activity in saline sodic soils with 12.5 mg N/kg soil.

In lentil, Rhizobium BK - 4 + Azotobacter AD increased the straw yield by 26 and 23 percent over uninoculated land Rhizobium BK – 4, respectively (Kumar et al. 1988).

Inoculation of lentil with Rhizobium increased nodulation and nitrogenase activity (Chandra, 1991 and Dhingra et al., 1988). But Kabi et al. 1990 did not find any effect of nodulation on number of nodules in lentil cv. Ashawa.

Most of the pulse growing area in India has poor bacterial status. Therefore, yield of legume can be stepped up substantially by

use of biofertilizers. Trials conducted under AICPIP at different locations during 1991-93 clearly revealed that the grain yield of chickpea, lentil, pigeonpea, moong and urd increased from 4-24 percent due to inoculation (Singh & Mishra 1998). Subba Rao and Tilak (1984) also found that grain yield of pigeonpea, chickpea and lentil increased by 16-65 per cent, 6-64 per cent and 20-63 per cent with inoculation over uninoculated control, respectively.

Combined use of culture showed encouraging results at Sabour. Inoculation of chickpea genotypes (C235, Pant G 114, BR 77 and HH 208) with Rhizobium along with N and P_2O_5 resulted in significantly increase in seed yield over only N and P as well as control (Singh et al. 1987).

Rhizobium inoculation increased the seed protein content (Jamwal et al. 1989), soil N content by 20 kg/ha (Sarkar et al. 1989) and response to fertilizer N in urd (Kaur 1991).

Concentration and uptake of P in mungbean and extractable P in soil increased due to Rhizobium inoculation as reported by Prasad and Ram (1986). Kothari & Saraf (1988) found better uptake of P in Rhizobium + Azotobacter chroococum than Rhizobium alone or its combination with Azospirillum brasilense. Maiti et al. (1988) observed 36-54 per cent increase in the nodule nitrogenase activity by Rhizobium. Prasad & Ram (1988) recorded an increase in uptake of Ca and its concentration in mungbean cv. Pusa Baishakhi with Rhizobium inoculation. Singh et al. (1990) reported that rhizobium increased P and Mn content in seed and straw both, while N and K content in straw only.

Bhandal et al. (1989) concluded that host (cultivars)-Rhizobium strains interaction was responsible for maximum nitrogen fixation.

Chandra and Pareek (1991) observed decrease in nodulation

with applied N in chickpea. Rai (1992) also observed that in Phaseolus vulgaris cultivars, application of higher level of N inhibited nodulation and nitrogenase activity without affecting seed yield. Verma and Rao (1972) reported that foliar spray of urea in mungbean had negative effect on efficiency of legume Rhizobium symbiosis. Veena et al. (1985) also revealed that nitrate application delayed the rate on N_2 – fixation and reduced the nodule development in chickpea. Negative effect on nodulation due to increasing doses of nitrogen in pigeonpea was also observed (Kaushik et al. 1995). But Sinha (1977) concluded that in all genotypes of pulses nodulation are not affected similarly by N application and at 75 kg N/ha, only 2 out of 20 genotype were affected. In greengram, the highest root nodule dry weight/plant was noticed with 30 kg N/ha (Bachchan 1994).

Phosphorus is the constituent of ATP, which is used in the process of conversion of atmospheric N to ammonia. Thereby, its requirements to pulse crops are high. Gupta & Bajpai (1982) Rhizobium inoculation efficiency increased with applied P in pigeonpea. Inoculation of black gram seed, which had been soaked in 20 percent potassium dihydrogen phosphate for 3 hrs, increased the survival of rhizobia on seeds. Treatment of P soaked or dry seed with Bavistin (carbendazim) gave yield of 424-437 kg/ha and gave the highest survival of rhizobia on seed (Hameed et al. 1988). In chickpea, Lakshman Rao and Singh (1983) obtained increase in the fresh weight of the nodules with the application of phosphorus and leghaemoglobin content of nodules was directly correlated with N_2-fixation. This is probably due to the fact that phosphorus stimulated the nodulation more through its effect on bacteria than on host. In the presence of phosphorus, the bacterial cell becomes motile and flagilate, a prerequisite for migration, whereas in the absence of phosphorus, the infection remains latent leading to the poor development of nodules

(Diener 1950). In a field trial on mungbean seed inoculated alone or combined with 25 or 50 kg P_2O_5/ha, yielded 0.93, 0.99 and 1.08 t/ha, respectively. Khade et al. (1988) observed that in chickpea nitrogen accumulation increased with rate of P application and was higher with Rhizobium inoculation. In bean-Rhizobium symbiosis from inoculation of Glomus macrocarpum at all P levels, showing increase in dry matter and seed production in shoot N and P concentration and N, P and K content, and in nodulation. P application and seed inoculation had beneficial effect on nodule dry weight/plants, number of branches/plant and nodule leghaemoglobin content (Rathore, 1992). Beneficial effect of phosphorus on nodulation has also been reported by Verma et al. (1988), Reddy et al. (1994) and Sharma et al. (1992).

Most of the cereals remove 3.2 to 5.3 kg P, pulses 4.5 to 5.5 kg P and oilseeds 7.8 to 11.5 kg P for producing one ton of grain. It is well known fact that to make 100 units of protein, plants need at least 16 units of N. Behind every ton of cereal grain, there is an N-uptake of 20-25 kg (equivalent to 90-100 kg urea at 50% efficiency). Behind every ton of cereal produced, there is an uptake of 8-12 kg P_2O_5 equivalent in replacement value to 56-84 kg DAP at 30% efficiency including residual effect. Behind every ton of cereal grain produced is an uptake of 25-30 kg K_2O, equivalent in replacement value to 72-87 kg MOP at 60% efficiency.

A good example of the P x Rhizobium interaction can be cited from the field data of the experiments conducted at Chandra Shekhar Azad University of Agriculture & Technology Kanpur with lentil as the test crops (Gupta & Sharma 1989). Rhizobium inoculation without P application had very little effect on N fixation (+3.1 kg/ha), the grain yield (+25 kg/ha) and protein yield (+7 kg/ha). Similarly, the corresponding increases with P application without rhizobium inoculation were 44, 42.3 and 52 kg/ha, respectively. Rhizobium

inoculation in conjunction with 72 kg P_2O_5/ha very significantly increased N fixation, grain yield and protein yield, the numbers being 54, 781 and 184 kg/ha, respectively. Apparently, the increase in N fixation, grain yield and protein yield due to interaction effect were 69, 323 and 125 kg/ha respectively. Such synergistic effect of rhizobium inoculation in increasing P use efficiency as revealed by increase in grain yield per kg of applied P_2O_5 and of P application in increasing efficiency of rhizobium inoculation should be harnessed by conjunctive use of these inputs. Besides having the beneficial effect of one on the other, rhizobium inoculation along with P application will have favourable effect on total factor productivity (Tiwari, 2002).

Prasad and Sanoria (1981) studied on chickpea gave seed yields of 1.01-1.11 t/ha with 50-150 kg P_2O_5/ha and 1.33 – 1.37 t with P + seed inoculation with rhizobium strain H_{45} + Azotobacter strain B_4, the highest being with 50 kg P_2O_5/ha inoculation. Seed protein content was highest (26.32%) with inoculation + 150 kg P_2O_5 and lowest (22.93%) with 50 kg P_2O_5.

Rickerl (1981) studied in field soil pH levels were 5 and 5.8 and soil P levels were 7, 55 and 105 kg/ha. The winter legume was harvested at full bloom and again to maturity. The effects of soil pH and P followed similar trends for each crop. Soil pH did not effect dry matter production but low P was detrimental to yield and nodulation at both pH levels. Above ground dry matter yields averaged over crops and pH levels were 641, 4327 kg/ha for soil P levels of 7, 55 and 105 kg/ha respectively and the corresponding N concentration were 3.12, 3.94 and 3.98%. Total N in the plant tissue was 20, 170 and 173 kg/ha or the soil P levels of 7, 55 and 105 kg/ha.

Singh et al. (1983) observed in field experiments during the rabi (winter) seasons growth, seed yield and quality of Cicer arietinum

increased with increasing levels of P_2O_5 from 0 to 60 Kg/ha; the economic optimum rate was 45.4 kg P_2O_5/ha. Rhizobium inoculation also significantly increased the growth, yield and quality, but phosphobactrin had no significant influence of them.

Manjunath et al. (1984) reported response of cowpea and pigeon pea to dual inoculation with rhizobium with or without added P (22 kg/ha) was studied in a P deficient non-sterile soil. Application of P increased nodulation and the number of endo-mycorrhizal spores in the root zone of the both legumes. Plants isolated with both organisms and supplemented with P recorded the highest shoot dry weight and N & K contents, indicates the need for the addition of a small amount of P to derive maximum benefit from dual inoculation with rhizobium.

Sharma et al. (1984) observed in legumes, N fixation due to inoculation with rhizobium culture helps in increasing the yield. Here phosphorus plays a key role since it is essential for the bacterial for the initial infection and nodulation of root system. For infection the cells must be in a mobile form and phosphorus has a pronounced effect on retention of this particular state.

Raju et al. (1984) studied in application of 40 and 60 kg P_2O_5/ha to 3 Cicer arietinum grown from inoculated seeds on a sandy clay loam soil given 3 t FYM/ha increased the 2-years av. seed yields by 15.9 and 22.1%, resp., compared with 20 kg P_2O_5/ha. The optimum economic rate was 45.4 kg P_2O_5/ha. FYM or inoculation did not affect yield.

Maurya and Sanoria (1986) reported the inoculation of chickpea seeds with two-rhizobium strain alone and with two Azotobacter strains and/or Pseudomonas increased the nodulation, root growth, seed yields, nutrient uptake and soil N content.

Thind et al. (1990) studied in pot trails with Vigna radiata, Cicer

arietinum & Vigna unguiculata grown in 12 soil types, utilization of 30, 60 and 90 kg P_2O_5/ha applied as a 32P-labelled DAP solution. 60 kg P_2O_5/ha gave the highest DM yields in 3 crops irrespective of soil type. Increasing P rates increased P uptake. Increasing rates of P decreased P utilization was low in Cicer arietinum (4.9-5.1%) and V. radiata (7.4-8.0%). Utilization of applied P varied in different soil types.

Tippannavar et al. (1990) reported that the addition FYM to soil had a beneficial effect on Rhizobium and increased the soil N-content. Cell density of bacterial was greatest at 100% conc. of extracts of ground FYM in eight strains tested, although there were significant differences between strains.

Raju et al. (1991) studied in trials with 3 chickpea cultivars grown on plots given FYM a rate equivalent to 10 kg N per ha or grown from seed inoculated with Rhizobium increasing P_2O_5 rate (20, 40 and 60 kg/ha) increased seed yields, nodulation and N, P and K uptake.

Raut and Kohire (1991) reported that in field trial s in 1980-83 at Parbhani, Maharashtra, chickpeas cv. BDN-9-3 were given seed inoculation with Rhizobium and 0, 25 or 50 kg P_2O_5/ha. Nodule dry weight increased from 550.3 to 669.7 mg/plant, number of nodules/plant increased from 21.0 to 26.2 and seed yield increased from 1.08 to 1.27 t/ha with rhizobium inoculation. Number and DW of nodules/plant increased with rate of P application in all years. Seed yield increased significantly with application of 25 kg P_2O_5/ha in 1981-82 only and with application of 50 kg P_2O_5/ha all 3 seasons. N accumulation increased with rate of P application and was higher with Rhizobium inoculation.

Jat et al. (1992) demonstrated at Jobner, Rajasthan, irrigated chick peas given 40, 30, or 20 kg P/ha produced seed yield of 1.17,

1.11 and 1.01 t/ha, respectively. N and P uptake (kg/ha) increased with P rate. Sowing rate of 60 or 80 kg/ha produced seed yields of 1.02 and 1.17 t, respectively, seed yield of cv. RS 11 was higher (1.19 t/ha) than those of RSG 2 or RSG 44 (1.05-1.06 t).

Carrasco-Lopoz (1998) reported in a field experiment in 1995-96 in Spain, chickpeas cv. Candil were seed inoculated with 2 stains of rhizobium or not inoculated and given the recommended N rate or no N. Seed yields were highest with seed inoculation.

Takankhar et al. (1998) conducted a field experiment in Maharashtra. Bengal gram Cv. BDN 9-3 was seed inoculated with rhizobium or not inoculated, and given 0-75 kg P_2O_5/ha and 25 or 50 kg N/ha. Seed inoculation and the application of N and P significantly increased P uptake. Seed yield was higher with inoculation (1.15 vs. 1.08 t/ha) and was not affected N rate. The application of 75-kg P_2O_5 produced the highest seed yield of 1.25 t/ha.

Alvarez and Leon (1991) studied a Glasshouse experiments were conducted to evaluate the nodulation and N-fixation capacity of 19 indigenous strains of R. leguminosarum by phaseoli on botil bean (P. coccineus sub sp. Coccineus) and the symbiotic response of several accessions of indigenous botil bean (varying in their seed-coat colour) to inoculation with one rhizobium strain. A wide variation in nodulation capacity between the rhizobial strains was observed. Nodule number and nodule dry weight/plant were found to be correlated with both shoot dry weight and shoot N accumulation. Mean nodule dry weights were inversely related to nodule number/plant. At 120 days after planting only 4 strains significantly increased both shoot dry weight and shoot N accumulation over the uninoculated control. Differences in nodulation and growth of inoculated plants suggested that seed cost phenotypes of botil bean respond differently to rhizobia.

Das et al. (1991) reported that the application of organic manures influenced the properties and nutrient availability in soils with varied organic matter and exchangeable Al status. The pH showed a decreasing trend at higher dose of manures. Humic and fulvic carbon contents did not show any definite trend. Available P increased after 12 days of incubation and reduced drastically thereafter. Amount of exchangeable K increased markedly till 24^{th} day and declined thereafter. The degree of decrease was more pronounced under low organic matter status soil than under high organic matter one. In general the exchangeable Ca content increased gradually up to 36 days while Mg content did not show any definite pattern. Overall efficiency of organic manures followed the trend: Poultry manure>Piggery manure>Farmyard manure. pH , humic and fulvic carbon contents showed differential patterns with nutrient availability at different intervals. The contribution of humic acid towards nutrient availability was highest under low organic matter status soil while in case of high organic matter status soil, fulvic acid showed the maximum positive correlation.

Kukreja et al. (1991) reported that the application of farmyard manure (FYM) increased organic carbon, total nitrogen and total microbial biomass significantly in soils of the plots receiving 90 t ha^{-1} of it annually for 20 years. The basal respiration level of the population at higher levels of carbon was less than that of the population at lower levels of carbon in soil during the period when soil respiratory activity had stabilized.

Milic et al. (1991) been reported that the effects of six Bradyrhizobium japonicum strains (26, 16, 518, 511, 10 and 1), with different capacity to produce growth regulators, on five soyabean varieties (NS-6, NS-10, NS-16 and Corsoy) were studied. The plants were grown to full maturity (14 weeks) in a greenhouse. The effects of

B. japonicum strains were tested through the number and dry matter mass of nodules and the amount of nitrogen taken up by the plants. The results obtained showed that the mass of nitrogen and dry matter mass of nodules are correlated with growth regulators produced by the strain of B. japonicum tested and negatively with the number of nodules formed on the plant.

Prasad and Rokima (1991) conducted a field experiment on rice-wheat rotation was started at the farm of university at Pusa in the year 1980-81 kharif season. The soil is Harpur clay loam (Calciorthent). Four levels of NPK fertilizers based on soil test values, viz. no NPK (F_0), 50 per cent NPK (F_1), 75 per cent NPK (F_2) and 100 per cent of optimum dose of NPK (F_3) were used as treatment in main plot. These treatments were given to each crop in each year. Each main plot was divided into 4 sub-plots in which sub-treatments, viz. no FYM or blue-green algae (BGA) (M_0), FYM (M_1), BGA (M_2) and FYM+BGA (M_3) were superimposed over NPK levels. FYM @ 10 t ha^{-1} before transplanting of rice and BGA @ 15 kg ha^{-1} of algal crust for rice after one week of transplanting of rice were added.In the nutrient balance sheet approach, it was found that N and P had positive and K had negative balance in soil. It showed increase in available N and P and decrease in available K in soil. Removal of K was more than that applied through treatments.

Upadhyay et al. (1991) conducted on the effect of N, P and S application to black gram (Vigna mungo) on the yield and transformation of P in an Inceptisol was studied. Although N application tended to increase all the four forms of P, the increase was statistically significant only in the case of total and organic P during the first year. The response of black gram was highest when before sowing. In the second year, the increase was not significant. All the four forms of P tended to increase due to P or S application

individually. N,P and S significantly increased grain yield. N dose on soil test basis in conjunction with Rhizobium inoculation was adjudged the best among N treatments.

Prasad and Maurya (1992) carried out an experiment during the rabi [winter] season, 1983-84, to study the effects of application of P_2O_5 at 0, 40, 80 or 120 kg/ha, with or without Rhizobium inoculation of seeds. P_2O_5 application and Rhizobium inoculation, alone or in combination, resulted in significant increases in growth, nodulation and yield, compared with the control. Increasing P_205 concentration resulted in corresponding increases in these parameters. The highest green pod yield was obtained with a combination of 120-kg P_20_5/ha and Rhizobium inoculation.

Singh and Bisoyi (1993) reported that the Biofertilizers such as Azolla, blue-green algae, and green manures for rice, Azotobacter and Azospirillum for wheat, millets and vegetables and number of years. Phospho-microorganisms for plantation crops were also important in Indian agriculture. The N fixation and biomass accumulation by Biofertlizers balancing of soil N are also discussed.

Ishaq et al. (1994) observed in a pot experiment Vigna faba cv. Giza 502 and Lens esculenta cv. Giza 370 were grown in sterilized clay loam or clay soil inoculated with vesicular arbuscular Mycorrhizae (VAM, Glomus and Gagaspora) and Rhizobium leguminosarum bv. Viceae and maintained at 30, 60 or 90 % water holding capacity (WHC). Shoot DM and N and P contents were higher in V. faba than L. esculenta and in the soil maintained at 60% WHC. Inoculation increased DM yield and N and P contents with a combination of VAM R. leguminosarum giving the best results. Inoculation was most effective at the Z lower soil WHC levels.

Sharma et al. (1995) studied in a field experiment in Uttar

Pradesh, India, good inoculation with Rhizobium and application of 40 kg P_2O_5/ha in chickpea (Cicer arietinum) either alone or in combination enhanced nodulation and yield significantly over the uninoculated control for two consecutive years.

Selvi and Ramaswami (1995) studied in a field experiment in 1989 at Killikulum, Tamil Nadu. Black gram [Vigna mungo] was grown on residual fertilizer after double cropped ride which received various combinations of NPK fertilizer rates, ZnSO<sub (4) >, S as CaSO<sub (4) >, herbicide treatment, FYM and green leaf manure. Availability of N, P and K in soil was increased with the previous application of the recommended NPK fertilizer + FYM. Seed yield (638 kg/ha) was highest in plots receiving the recommended NPK fertilizer + 25 kg ZnSO<sub (4) > applied only once in the cropping sequence. The N, P and K uptakes were also highest in the latter treatment.

Senaratne and Ratna Singh (1995) studied were conducted on paddy soils to determine N_2 fixation, growth, and N supplying ability of some green-manure crops and pulses. In a 60 days pot trial, sunnhemp (Crotalaria juncea) produced a significantly higher DM content and N yield than Sesbania sesban, S. rostrata, cowpeas (Vigna unguiculata), and black gram (V. mungo), deriving 91% of its N content from the atmosphere. DM production and N yield by the legumes were significantly correlated with the quantity of N_2 fixed. In a lowland filed study at 2 sites in Sri Lanka involving sunnhemp, black gram, cowpeas, and mung beans (V. radiata), sunnhemp produced the highest stover yield and stover N content, accumulating 160-250 kg N/ha in 60 d, and showed great promise as a biofertilizer for rice. The pulses showed good adaptability to rice-based cropping systems and produced a seed yield of 1.13-2.08 t/ha, depending on the location, species, and cultivar. Significant inter-and intra-specific differences in stover N content were evident among the pulses, with

black gram having the highest N (104-155 kg N/ha). In a trial on sequential cropping, groundnuts (Arachis hypogea) had higher N_2 fixation and residual N effect on the succeeding rice crop than cowpeas, black gram, mung beans, and pigeonpea (Cajanus cajan). The growth and N yield of the rice crop were positively correlated with the quantity of N_2 fixed by the proceeding legume crop.

Toor et al. (1995) reported that the organic manures have long been recommended for improving soil health and crop yield. Poultry manure (PM), compared to farm yard manure (FYM), is a better source of nutrients Generally, poultry manure is used as substitution of N and after the application, only fertilizer-N application is reduced for the crop. The present investigation was planned to study the effect of continuous application of poultry manure (PM) to supply graded levels of P to the crop and its effect on available N, P and K status of soil, using control and FYM treatments for comparison. A long-term field experiment conducted on an alluvial, sandy loam soil taking maize-wheat rotation for 10 years i.e., from *kharif*, 1983 to *rabi*, 1992. The experimental field was normal in pH and salt content. Available N, P and K of 80, 15 and 175 kg ha^{-1} to only maize in main plots and single super-phosphate (SSP) @ 0, 20, 40, 60 and 80 kg P_2O_5 ha^{-1} to both maize and wheat in sub-plots using split-plot design of experiment. Nitrogen was applied @ 120 kg ha^{-1} as basal dose through urea. Surface soil samples (0-15cm) were collected after the completion of 10 cycles of the crop rotation and were analyzed for organic carbon (O.C.), available N, P and K. Continuous use of organic manures improved the O.C. content of soil significantly at both the levels of their application and PM gave higher O.C. content than FYM. Increasing P_2O_5 levels, through SSP, also improved the O.C. content in the soil. The highest change in O.C. from 0.371 to 0.517% was obtained with the application of 60 kg P_2O_5 ha^{-1} in FYM plus 80 kg

P_2O_5 ha^{-1} through SSP treatment. Long-term use of manures also improved the available N content of soil. But, significant improvement was observed only when they were applied to supply 60 kg P_2O_5 ha^{-1}. Higher rates of application of the manures gave significantly better results than the lower doses. Both the manures were equally efficient in improving available N. the available N content in treatments receiving higher levels of PM and FYM was 138 and 135-kg ha^{-1}, respectively. Greater levels of inorganic P alone resulted in a decrease in available N status of the soil.

Ghosh et al. (1995) studied a fixed plot field study on long range fertility management in soybean-wheat sequential cropping under rainfed condition was initiated in 1973 at Hawalbagh Farm of V.P.K.A.S., Almora (1250m AMSL) with a view to study the long range effect of organic and inorganic fertilization on crop productivity, soil properties and nutrient dynamics. The experiment was laid out in R.B.D. with six replication in a sandy loam alluvial soil. i. e. [pH 5.86, per cent clay 5.8, cation exchange capacity 8.7 c mol (p^+) kg^{-1} soil, bulk density 1.45 (g/cm^{-3}) water holding capacity 31.5%, organic carbon 0.63%, available N 239 kg ha^{-1}, available P 39 kg ha^{-1}, available K 107 kg ha^{-1}]. The treatments comprised no fertilization ($N_0K_0P_0$), 20 kg N + 35.2 kg P ha^{-1} (N-P), 20 kg N + 33.2 kg K ha^{-1} (N-K), 20 kg N + 35.2 kg P + 33.2 kg K ha^{-1} (N-P-K), 20 kg N + FYM 10 t ha^{-1} (N-FYM) and 20 kg N + 35.2 kg P + 33.2 kg K + FYM 10 t ha^{-1} (N-P-K-FYM). These treatments were applied in soybean and succeeding wheat was grown on residual fertility. Long term fertilization treatments involving FYM had more pronounced beneficial effect on crop productivity and soil properties. The average yield reduced to the tune of 76.5, 73.6, 64.5, 43.9 and 17.0% in soybean and 62.7, 56.9 49.6 38.3 and 15.5% in wheat over N-P-K-FYM under treatments $N_0P_0K_0$, N-K, N-P, N-P-K and N-P-K-FYM, respectively. The chemical

fertilizers did not adversely affect the soil physical properties except bulk density.

Sharma (1995) observed a long term fertilizer experiment was initiated during 1972-73 (rabi) to study the effect of continuous application of manures and fertilizers on crop yields and nutrients uptake and to monitor changes in physical, chemical and microbiological parameters of soil under maize-wheat cropping system. Maize and wheat grain yields decreased from 2.98 and 2.27 t ha^{-1} during 1972-73 almost zero level during 1994-95. An integrated nutrient supply through FYM and chemical fertilizers sustained higher yield levels of about 45-50 q ha^{-1} of maize and 35-40 q ha^{-1} of wheat over a period of 22 years. Application of lime with chemical fertilizers also sustaining comparable yield levels as to NPK + FYM, seems to be an alternative practice in acid Alfisols in the absence of farmyard manure.

Bhatnagar and Chaplot (1996) studied an experiments in 1986-92 at Banswara, Rajasthan the crop sequences maize/wheat, urdbean [Vigna mungo]/wheat and maize/chickpeas [Cicer arietinum] were grown with different NPK fertilizer rates to select the time of inclusion of legume in the cropping sequence and the beneficial effect of green manuring with V. unguiculata in a cereal/cereal system. The urdbean/wheat system with full fertilizer application (20 kg N + 40 kg P + 20 kg K and 120 kg N + 40 kg P +20 kg K/ha for legume and cereal, respectively) gave significantly higher total wheat equivalent yields (6130 kg/ha) and net returns than the maize/wheat and maize/chickpea systems.

Shivananda et al. (1998) reported the dynamics of nitrogen, phosphorus, potassium and sulfur in French bean (Phaseolus vulgaris) cv. Arka Komal at preflowering, flowering and harvest stages were studied in a pot experiment. Of the three nitrogen sources

compared, ammonium sulfate recorded higher yield followed by vermicompost and FYM. Uptake of N by French bean was highest in ammonium sulfate treated soils followed by FYM. There was remobilization of N, P, K and S from leaves and roots to the pods. The organic amendments favoured root growth, whereas ammonium sulfate suppressed it.

Kwatra et al. (1999) reported that the field experiments were conducted during 1988-90 at Faizabad, Uttar Pradesh, to determine the effect of planting pattern and fertilizers on yield attributes and nutrient uptake in pea/mustard [Brassica juncea] intercropping. Yield attributes and yield of pea and mustard were maximum in their sole stands during both years. Amongst various intercropping treatments, paired planting of pea at 22.5 cm spacing with 140:120:80 kg NPK/ha resulted in significantly higher yield attributes, seed yield (1176 and 1296 kg/ha) of pea and nutrient uptake than other planting patterns. However, alternate planting of mustard at 22.5 cm with 140:120:80 kg NPK/ha produced significantly higher seed yield of mustard (1898 and 1787 kg/ha) than paired planting at 22.5 cm. The uptake of NPK was significantly higher in the same treatment.

Namdeo and Gupta (1999) observed in a field experiment during the kharif seasons of 1994-95 and 1995-96 in Sehore, Madhya Pradesh, India, C. cajan was seed inoculated with Rhizobium and/or phosphorus solubilizing bacteria (PSB, Pseudomonas striata) and given 50, 75 or 100% of the recommended fertilizer rate (RFR, 20:50 kg NP/ha). Rhizobium inoculation increased nodule number and dry weight and shoot dry weight. Rhizobium, PSB and Rhizobium + PSB with 100 % RFR produced 13.8, 9.9 and 20.4% higher grain yield, respectively, than 100% RFR alone. Rhizobium + PSB with 75% RFR gave a saving of 25% of the chemical fertilizer by producing yield.

Das et al. (1999) observed in a pot experiment was conducted to

study the effects of Rhizobium and VA- Mycorrhizae on green gram (cv. Nayagarh local) in acid lateritic soil (Alfisol) of Central Agricultural Research Farm, Bhubaneswar. Three P-sources namely RP, SSP and their mixture (1:1) and organic matter were included in the experiment with and without lime. The dry matter yield and N, P and K uptake of green gram harvested at 65 days of growth were significantly higher due to dual inoculation, and were more pronounced when amended with lime. The investigation suggested that dual inoculation of Rhizobium and VA-mycorrhiza in presence of organic matter along with application of Mussoorie rock phosphate improved the growth and yield of green gram.

Rao and Rao (1991) reported this study from a part of a field experiment in progress since kharif 1992 at the Indian Institute of Soil Science farm, Bhopal with soybean-wheat system on Typic haplustert soil (pH 8.2 (1:2 soil water), having clay loam, organic carbon 4.9 g kg^{-1}, available N 250 kg ha^{-1} and available (Olsen) P 1.97 mg kg^{-1} and K 420 kg ha^{-1}. Soybean (Punjab 1) and wheat (WH 147) crops in the rotation were repeated upto 1996 (4 rotations). The treatments consisted of four rates of FYM (0.64% K on dry-weight basis) (0, 11, 22 and 44 kg P ha^{-1}) in sub-plot with four replications in split-plot design. FYM was applied only to soybean, 10-20 days before sowing. Phosphorus was applied as per the treatments along with recommended doses (25-kg K ha^{-1}) of potassium and nitrogen to both soybean (30 kg N ha^{-1}) and wheat (120 kg N ha^{-1}). Other nutrients viz. S @ 25 kg ha^{-1} and Zn 6 kg ha^{-1} were applied to soybean and 20 kg ha^{-1} S and no zinc to wheat. Total K added to soil during experimental period (1992-96) through FYM and MOP. The $CaCl_2$ and NH_4O as extractable K status increased with increase in the level of FYM from 0 to 16 t ha^{-1}, indicating higher magnitude of $CaCl_2$ and NH_4OAc-K in soils in the absence of P. similarly, $CaCl_2$ and NH_4OAc-K values were

found to be almost similar at 22 and 44 kg P ha^{-1} as the drymatter yield as well as K uptake did not increase significantly beyond 22 kg P ha^{-1}. However, higher K uptake was recorded due to optimum P supply to crop, which may be attributed to balanced fertilization. The combined effect of P and FYM was more prominent in uptake of K by straw and total K uptake rather than their individual applications.

Ali et al. (2000) observed the nutrient imbalance is one of the major abiotic constraints limiting productivity of pulses. The inbuilt mechanism of biological N_2 fixation enables pulse crops to meet 80-90% of their N requirements, hence a small dose of 15-25 kg N/ha is sufficient to meet the requirement of most of the pulse crops. However, in new cropping systems like rice-chickpea, a higher dose of N (30-40 kg/ha) showed beneficial effect. Phosphorus deficiency is wide spread and most of the pulse crops have shown good response to 20-60 kg P_2O_5/ha depending upon nutrient status of soil, cropping system and moisture availability. Response to K application is location specific. In the recent years, use of 20-30 kg S/ha and some of the micronutrients such as Zn, B, Mo and Fe have improved productivity of pulse crops. Band placement of phosphatic fertilizers and the use of biofertilizers enhance efficiency of applied and native P. Foliar nutrition of some miocronutrients was effective. The amount and mode of application is determined by native nutrient content, associated or preceding crop, moisture availability and the genotypes to be grown. In a cropping system, 25% higher dose of nitrogen is recommended to pulse crops after rice, sorghum and maize than those grown after urdbean, mung bean or fallow.

Mani and Yadav (2000) observed that to producing more food to feed the ever-increasing population from shrinking land and less water, without eroding the ecological foundation will be an uphill task. The surest means to tide over this challenge is through

environmentally sustainable framing method. Keeping in view the above mentioned objective a field experiment was conducted at S.D.I. experimental farm, Allahabad in order to find out the response of M.R.P., Rhizobium and FYM on yields of Cicer arietinum and the availability of N, P, K in soil. The whole effect of MRP, FYM and Rhizobium gave seed production to the extent of 45.2% which was higher than the control experiment showed that the yield of chickpea, when MRP, FYM and Rhizobium were applied was 2033.3 kg/ha as compared to 1400 kg/ha obtained in control. The overall effect of MRP and FYM with Rhizobium interaction on soil may reduce the possibility of the soil pollution. FYM application has proved beneficial in improving the physical, chemical and biological properties of soil and its effect on interaction with MRP in reducing the soil pollution may be an important contribution of soil humus and Rhizobia inoculation.

Singh et al. (2000) observed in rice-chickpea cropping sequence that organic manures showed significant yield when compared with control (27.7 q/ha rice and 8.5 q/ha chickpea). The significant grain yields of rice and chickpea were 49.9 and 13 q/ha with Sesbania rostrata followed by poultry manure (49.4 and 14.3 q/ha), $N_{80}P_{50}K_{30}$ kg/ha (48.9 and 10.3 q/ha), sunnhemp (45.6 and 11.3 q/ha), Nadep compost (44.6 and 11.6 q/ha), farmyard manure (41.3 and 10.5 q/ha) when compared with control. The other crop viz. rice, rainfed niger, sunflower, soybean, summer sesame, rice-wheat-cropping system also showed significant results when treated with organic manure.

Verma and Yadav (2001) carried out a field experiment during rabi season of 1999-2000 to find out the effect of Mussoorie Rock Phosphate (MRP) (40kg P_2O_5/ha.) and FYM (5 & 10 t/ha) with rhizobium culture on plant growth, nodulation, biomass production and grain yield of chickpea at the experimental farm of Sheila Dhar

Institute of Soil Science, Allahabad. The combined effect of MRP application with rhizobium, MRP + FYM with rhizobium significantly increase the plant height, nodulation biomass production and grain yield. The combined effect MRP+FYM (5 t/ha) with rhizobium culture was found to be more beneficial in reducing soil pollution over the control and other treatments.

Mani and Yadav (2002) conducted a field experiment with sandy clay loam soil to study the effect of Rhizobium, phosphorus and FYM on yield of grain, straw and N-fixation in soil by green gram (Vigna radiata L.). Rhizobium was applied @ 3 kg ha^{-1} for the seed inoculation, either alone or along with two doses of phosphorus –30 kg and 60 g P_2O_5 per ha^{-1}, or two doses of FYM-5 t and 15 t ha^{-1}. Rhizobium when used singly, increased significantly the yield of grain, straw and N-fixation in soil. Phosphorus when use alone significantly increased the yield of grain but did not result into any noticeable increase in N-fixation. FYM when used alone, did not respond to increase the yield. Interaction of Rhizobium, phosphorus and FYM showed better response on yield of grain, straw and N-fixation. Hence, in conclusion it can be said that judicious use of biofertilizers along with chemical fertilizer and organic manure increased the production of crop and maintained the soil health.

Chapter III

Materials and Methods

Chapter-III

MATERIALS AND METHODS

Details of the materials used and techniques followed during the present investigation have been dealt within this chapter.

Experimental Site

The site for experiments was Agricultural Farm of Sheila Dhar Institute of Soil Science, which is located near Mumfordgunj at Allahabad. The agricultural farm is being irrigated by tube-well water supplied by the Jal Sansthan, Allahabad. The field experiments were conducted during the year 2000 to 2002.

Climate

The climate of Allahabad is known for its cold winter and intolerable summers. The average rainfall is about 82.1 cm and average temperature varied from 32.4 to 36.0°C, with mean humidity is of about 64 percent.

Soil Characteristic

Mostly soil of Allahabad district is old alluvial soil. The Sheila Dhar Institute Farm has also alluvial soil, belonging to order – Inceptisol, sub order – Ochrepts, Great group – Eurocrepts, Sub group – Typic Eurocrepts, Family – Coarse silty, mixed thermic, Series – Natches and the texture of soil is sandy clay loam. Soil is generally deficient in nitrogen, organic carbon and zinc, moderate in phosphorus and sufficient in potassium.

Collection of Soil Samples

Bulk soil samples (0-15 cm) were collected at pre-sowing and

post harvesting stage with the help of an auger from various parts of the plot for the experimental purpose.

Preparation of Soil Samples for Analysis

The representative soil samples of about 1.0-Kg of each experimental plot were brought to laboratory and air-dried in shade. Wooden hammer was used for crushing and pounding the clods. After thorough mixing they were again and again crushed thoroughly, mixed and finally passed through the 2 mm sieve. The soil samples thus prepared were kept in the same polythene bags and staked in the soil racks for analysis.

Collection of plant samples

Plant samples were taken at harvesting from all the replications. The samples were oven dried, ground and subjected to chemical analysis.

Methods employed for soil and plant Analysis

Soil Analysis

pH (1:2.5 Soil Water suspension)

pH value was measured by the pH meter as described by Chopra and Kanwar (1991).

Organic Carbon

Organic carbon was determined by the modified Walkley and Black's method (Piper 1960) in which a known amount of the soil was digested with potassium dichromate and sulphuric acid. The excess of chromic acid was blank titrated with standard ferrous ammonium sulphate as described by Jackson (1973).

Electrical Conductivity

Electrical conductivity dSm^{-1} at 25°C of saturation extract was determined with the help of conductivity meter as outlined by Jackson (1973).

Available Nitrogen

Available nitrogen was estimated by Kjeltech. Auto Analyzer (Alkaline Potassium Permanganate method) as described by Chopra and Kanwar (1991).

Available Phosphorus

Available phosphorus content of soil was estimated as described by Chopra & Kanwar (1991) (Olsen's $NaHCO_3$ Method).

Available Potassium

Neutral N-ammonium acetate solution was used as extractants for available K, which was analyzed with the help of a flame photometer (Lal Singh, 1987).

Micronutrients content in soil

Available Zinc, copper, iron and manganese was determined by a method of Lindsay and Norvel (1978) using DTPA (Di-ethylene Tri-amine Penta-acetic Acid) solution and AAS (Atomic Absorption Spectrophotometer).

Preparation of DTPA Solution

DTPA solution was used to extract the available heavy metals in soil samples.

1.97g (0.05M) DTPA power, 13.3ml (0.1M) Tri-ethanol amine

and 1.47g (0.01M) Calcium chloride were dissolved in distilled water and the volume was made up to 1 litre after adjusting the pH to 7.3.

Extraction of Soil with DTPA Solution

To 10g soil 20ml DTPA solution was added and the contents were shaken for two hours and then filtered through filter paper No. 42. This extract was utilised for the determination of available heavy metals by AAS.

Plant Analysis

Tri-acid digestion of plant sample

Digestion was carried out using a 5:2:1 mixture of conc. HNO_3, $HClO_4$ and conc. H_2SO_4.

One g of ground plant material was placed in 100-ml conical flask and 10-ml tri-acid mixture was added. The contents were heated on a hot plate at low heat for 30 minutes and the volume was reduced to about 5ml or changes the colour up to colourless or white.

After cooling the conical flask 20-ml distilled water was added and contents filtered through whatman No. 2 filter paper into a 100-ml of volumetric flask and the volume is made up with distilled water. This solution was used for the determination of P, K, Fe, Mn, Zn and Cu.

Carbon and Nitrogen

Carbon and nitrogen were determined by CHN Auto analyser (Duma's method) as described by Lindsay and Norvel (1978).

Table 3.1: Physicochemical properties of the initial soil samples of S. D. I. Farm Allahabad.

Treatment	pH	EC (dSm^{-1})	OC (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av.Zn (ppm)	Av.Cu (ppm)	Av.Fe (ppm)	Av.Mn (ppm)
T_0	8.5	0.32	0.53	170.0	26.4	601	4.08	5.32	4.40	27.72
T_1	8.5	0.31	0.54	170.3	25.8	603	3.85	5.37	4.29	27.50
T_2	8.4	0.32	0.50	166.3	26.8	599	3.93	5.28	4.29	27.00
T_3	8.5	0.34	0.52	168.0	24.4	595	4.06	5.24	4.30	27.08
T_4	8.4	0.30	0.53	167.5	25.0	597	4.00	5.36	4.35	27.65
T_5	8.3	0.30	0.51	167.5	25.0	604	4.04	5.30	4.39	26.68
T_6	8.4	0.32	0.52	169.0	24.9	608	3.98	5.30	4.36	26.65
T_7	8.3	0.33	0.50	168.0	26.7	602	3.92	5.28	4.32	26.92
T_8	8.5	0.30	0.50	170.0	26.3	596	3.89	5.34	4.30	26.72
T_9	8.5	0.34	0.52	170.3	25.5	598	4.00	5.35	4.40	27.00
T_{10}	8.3	0.31	0.54	169.8	26.2	600	4.06	5.31	4.37	27.45
T_{11}	8.3	0.32	0.53	168.5	24.8	602	3.87	5.30	4.39	27.50
T_{12}	8.4	0.34	0.54	168.7	26.0	607	3.93	5.27	4.36	27.50
T_{13}	8.5	0.30	0.52	167.4	26.1	605	3.99	5.25	4.30	27.70
T_{14}	8.4	0.34	0.51	167.6	25.7	599	3.94	5.29	4.33	27.66
T_{15}	8.4	0.32	0.53	169.3	25.5	598	3.86	5.32	4.33	27.60
T_{16}	8.3	0.33	0.51	170.0	25.7	600	3.85	5.35	4.32	27.64
T_{17}	8.4	0.32	0.51	168.0	26.3	604	3.90	5.36	4.31	26.90

Field Experiment

A field experiment entitled "Studies on Integrated Nutrient Management with Special reference to biofertilizers" on growth and yield parameters, nutrient content in plants and nutrient status of soil was conducted at the Sheila Dhar Institute of Soil Science Experimental Farm in a factorial design laid out as Randomized Block Design in two experiments having three factors [viz.(i) Rhizobium, Phosphorus and F.Y.M. and (ii) Rhizobium, NPK and F.Y.M.] containing eighteen treatments with three replications in each. The size of the micro plot was 1 m^2.

Rhizobium Culture

Rhizobium inoculation was done in concentration solution of 10% sugar mixed with rhizobium culture @ 250 g/10 kg seed and mixing with seed. The treated seed were dried in shade for 2 to 3 hours and then used for sowing immediately.

Experiment No. I

A field experiment was laid out during summer season of 2000-2001 in factorial experimental (R.B.D.) with eighteen treatment combinations having three replications. The total number of plots was 54. The treatment of Rhizobium, phosphorus & F.Y.M. were allotted as follows:

1. Levels of rhizobium applied: 2 (a) Un-inoculated (b) Inoculated: Seed inoculation of Rhizobium leguminosarum @ 250 g 10 kg^{-1} seed.
2. Levels of phosphorus applied: 3 (0, 30 and 60 kg P_2O_5 ha^{-1})
3. Levels of F.Y.M. applied: 3 (0, 5 and 15 t ha^{-1})
4. Total treatment combinations: Rhizobium levels × Phosphorus levels × F.Y.M. levels = 2 × 3 × 3 = 18
5. Replications : 3

6. Total number of treatments: $18 \times 3 = 54$
7. Size of plot: 1×1 m^2
8. Test crop: Green gram (Vigna radiata) var. K-851
9. Seed rate : 20kg ha^{-1}
10. Date of sowing: 7th March, 2001

Table 3.2: Treatments combination along with their abbreviated forms.

S.N.	Treatments	Abbreviated for figures
1.	Control	T_0
2.	F.Y.M. (5 t ha^{-1})	T_1
3.	F.Y.M. (15 t ha^{-1})	T_2
4.	Phosphorus (30 kg P_2O_5 ha^{-1})	T_3
5.	Phosphorus (30 kg P_2O_5 ha^{-1}) + F.Y.M. (5 t ha^{-1})	T_4
6.	Phosphorus (30 kg P_2O_5 ha^{-1})+ F.Y.M. (15 t ha^{-1})	T_5
7.	Phosphorus (60 kg P_2O_5 ha^{-1})	T_6
8.	Phosphorus (60 kg P_2O_5 ha^{-1}) + F.Y.M. (5 t ha^{-1})	T_7
9.	Phosphorus (60 kg P_2O_5 ha^{-1}) + F.Y.M. (15 t ha^{-1})	T_8
10	Rhizobium inoculated	T_9
11	Rhizobium inoculated + F.Y.M. (5 t ha^{-1})	T_{10}
12	Rhizobium inoculated + F.Y.M. (15 t ha^{-1})	T_{11}
13	Rhizobium inoculated + Phosphorus (30 kg P_2O_5 ha^{-1})	T_{12}
14	Rhizobium inoculated + Phosphorus (30 kg P_2O_5 ha^{-1}) + F.Y.M. (5 t ha^{-1})	T_{13}
15	Rhizobium inoculated + Phosphorus (30 kg P_2O_5 ha^{-1}) + F.Y.M. (15 t ha^{-1})	T_{14}
16.	Rhizobium inoculated + Phosphorus (60 kg P_2O_5 ha^{-1})	T_{15}
17.	Rhizobium inoculated + Phosphorus (60 kg P_2O_5 ha^{-1}) + F.Y.M. (5 t ha^{-1})	T_{16}
18.	Rhizobium inoculated + Phosphorus (60 kg P_2O_5 ha^{-1}) + F.Y.M. (15 t ha^{-1})	T_{17}

The soil was incorporated with phosphorus at above mentioned doses in the form of S.S.P. (16 % P_2O_5). S.S.P. was applied @ 0, 30 and 60 kg P_2O_5 ha^{-1} as basal dose according to the treatment. FYM were applied @ 0, 5 and 15 t ha^{-1} as broadcasting method according to the treatments, before 20 days of sowing. Rhizobium inoculation were applied @ 250 g of culture 10 kg^{-1} seed. The soil was mixed with the help of stick and made suitable for sowing of crop. The plot was irrigated with tap water whenever required.

Green gram crop was harvested on 17th June 2001 and straw & grain yield was recorded. Soil and plant samples were collected just after harvesting of crop from all the plots, dried processed and stored for the analysis as per method.

Different factors i.e. rhizobium, phosphorus and FYM were comprised in 18 treatments as given in table 3.2.

Experiment No. II

A field experiment was conducted in winter (rabi) season during 2001-02. The Lentil cv. T- 36 was sown as test crop in the same plots in which green gram was grown during 2000-01. The treatments of rhizobium, NPK and FYM were alloted as follows:

1. Levels of rhizobium applied: 2 (a) uninoculated (b) inoculated: seed inoculation of Rhizobium leguminosarum @ 250g 10 kg^{-1} seed.
2. Levels of NPK applied: 3 [0, 50% (15:40:30) and 100% (30:80:60)].
3. Levels of FYM applied : 3 (0, 10 and 20 t ha^{-1})
4. Total treatment combinations: Rhizobium levels × Phosphorus levels × FYM levels = 2 × 3 × 3 = 18.
5. Replications : 3
6. Total number of treatments: 18 × 3 = 54
7. Size of plot : 1 × 1 m^2.

The soil was incorporated with NPK fertilizers @ 50% NPK (15kg N: 40kg P_2O_5: 30kg K_2O ha^{-1}) and 100% NPK (30kg N: 80kg P_2O_5: 60kg K_2O ha^{-1}) in the form of urea, S.S.P. and M.O.P., respectively. FYM were applied @ 0, 10 and 20 t ha^{-1} as broadcasting method according to the treatments, before 20 days of sowing. Rhizobium inoculation were applied @ 250 g culture 10 kg^{-1} seed. The seeds were sown @ 70 kg ha^{-1} on 10th November 2002. All plots were irrigated from time to time whenever was required with tap water.

Table- 3.3 Treatments combination along with their abbreviated forms.

S.N.	Treatments	Abbreviated for figures
1.	Control	T_0
2.	F.Y.M. (10 t ha^{-1})	T_1
3.	F.Y.M. (20 t ha^{-1})	T_2
4.	50 % NPK (15:40:30)	T_3
5.	50 % NPK (15:40:30) + F.Y.M. (10 t ha^{-1})	T_4
6.	50 % NPK (15:40:30) + F.Y.M. (20 t ha^{-1})	T_5
7.	100 % NPK (30:80:60)	T_6
8.	100 % NPK (30:80:60) + F.Y.M. (10 t ha^{-1})	T_7
9.	100 % NPK (30:80:60) + F.Y.M. (20 t ha^{-1})	T_8
10.	Rhizobium inoculated	T_9
11.	Rhizobium inoculated + F.Y.M. (10 t ha^{-1})	T_{10}
12.	Rhizobium inoculated + F.Y.M. (20 t ha^{-1})	T_{11}
13.	Rhizobium inoculated + 50 % NPK (15:40:30)	T_{12}
14	Rhizobium inoculated + 50 % NPK (15:40:30) + F.Y.M. (10 t ha^{-1})	T_{13}
15.	Rhizobium inoculated + 50 % NPK (15:40:30) + F.Y.M. (20 t ha^{-1})	T_{14}
16.	Rhizobium inoculated + 100 % NPK (30:80:60)	T_{15}
17.	Rhizobium inoculated + 100 % NPK (30:80:60) + F.Y.M. (10 t ha^{-1})	T_{16}
18.	Rhizobium inoculated + 100 % NPK (30:80:60) + F.Y.M. (20 t ha^{-1})	T_{17}

The lentil crop was harvested on 27th March 2002. Weight of grain and straw yields were recorded for each plot after harvesting of the crop. Soil and plants samples were collected after harvesting of the crop from all the plots, dried, processed and stored for the analysis as per method. Different factors i.e. rhizobium, NPK and FYM were comprised in 18 treatments as given in table 3.3.

Statistical Analysis

Statistical analysis was done with the help of Sum of Square (S.S.) and Degree of Freedom (D.F.) as described by Singh and Verma (1984).

The method of analyzing the data has been illustrated in the following way:

(i) Tabulation: The observed data were tabulated according to treatments and replications.

(ii) S.S. for different sources of error.

(a) Correction factor (C.F.) = $\sum \frac{Rt^2}{nk}$

Where, $\sum Rt$ = Total of all the variates/replications.

n = Number of variates/replications.

k = Number of lots/treatments.

(b) Total S.S. = $(X_1^2 + X_2^2 + X_3^2 + ... + X_{kn}^2) - C.F.$

Where, X_1, X_2, X_3 .... X_{kn} are variates/data.

(c) S.S. due to variates/replications = $\frac{T_1^2 + T_2^2 + ...T_n^2}{k} - C.F.$

Where, T_1, T_2 ..... T_n are total of different lots/treatments

(d) S.S. due to lots/treatments = $\frac{Rt_1^2 + Rt_2^2 + \ldots\ldots Rt_k^2}{n}$ – C.F.

Where, Rt_1, Rt_2 ... Rt_k are total of different variates/replications.

(e) S.S. due to error=(Total S.S.)–(S.S. due to variates/replications) –(S.S. due to lots/replications)

(f) M.S. due to lots/treatments = $\frac{\text{S.S. due to lots / treatments}}{(k-1)}$

(g) M.S. due to error = $\frac{\text{S.S. due to error}}{(n-1)\,(k-1)}$

(h) Variance ratio = $\frac{\text{M.S. due to lots / treatments}}{\text{M.S. due to error}}$

(iii) Standard Error (S.E.) = $\sqrt{\frac{2V_E}{n}}$

Where, V_E = Variance due to error

n = number of replications

(iv) Critical Difference (C.D.) = S. $E_{diff.} \times t_{5\%}$ ($t_{5\%}$ = 2.228)

The observed value of F was compared from the tabulated F – value at 5% and 1% level of significance.

Chapter IV

Results and Discussion

Chapter IV

RESULTS AND DISCUSSION

This Chapter embodies the results obtained from present investigation entitled on "integrated nutrient management with special reference to biofertlizers." The data were recorded regarding the evaluation of integrated nutrient management in respect of their effect on soil properties, yield attributes and nutrient content of green gram and lentil crop. The findings are being discussed, elucidated and interpreted in the light of the accepted principal of soil science and finding of research work done in India and abroad to understand the cause and relationship. The results have been described and assessed their feasibility to the peasantry and their relative contribution in furtherance of knowledge under following heads:

1. Plant growth and yield attributes as affected by different treatments.
2. Nutrient contents of crops.
3. Changes in pH and electrical conductivity of soil.
4. Changes in nutrient status of soil.

Experiment I

A field experiment was conducted with sandy clay loam soil in the summer season of year 2000-2001 to study the effect of rhizobium, phosphorus and FYM on soil and plant by green gram (Vigna radiata L.) var. K-851. Rhizobium was applied by seed inoculation @ 250 gram of culture/10 kg seed, either alone or along

with three levels of phosphorus i.e. 0, 30 and 60 kg P_2O_5 ha^{-1} and three levels of FYM i.e. 0, 5 and 15 t ha^{-1} in 18 different treatments combination. The results and findings obtained from the experimental plots has been recorded in Table 4.I.1 to 4.I.22and discussed thoroughly are as follows:

Growth and yield attributing characters of green gram

The data pertaining to growth and yield attributing characters of green gram i.e. plant height (30 and 60 days after sowing) and yield of grain and straw have been summarized in table 4.I.1-4.I.4.

Height of green gram

The variations in height of plant at different growth stages as affected by different treatments at the field condition are recorded in table 4.I.1 and 4.I.2. The application of rhizobium inoculation significantly increased the growth of plant (30 and 60 days after sowing). The height of plant (30 DAS) was observed maximum in the treatment T_{17} which contained rhizobium inoculation + 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1}. It increased to the extent of 8.23% over control. The plant height 30 DAS was observed non-significant due to the application of FYM level. Plant height (30 DAS) was observed significantly increased with the application of P_2O_5 alone to the extent of 18.0 cm. The minimum increase was observed (30 DAS) in the treatment T_5 (FYM 15 t ha^{-1} + 30 kg P_2O_5 ha^{-1}) to the extent of 17.3 cm rest over the control (17.0 cm). FYM was not much beneficial to the height of plant (30 DAS) because FYM is a slow releasing nutrient supplier to the soil. The height of plant (60 DAS) increased 16 % in treatment T_{15} and T_{17} over the control, which was the maximum height of plant to the extent of 44.3 cm. Another treatment T_{13} gave 15.7 % higher increase in growth over the control. The treatment T_{14} and T_{16} gave similar growth i.e. 44.0 cm, at 60 DAS to the extent of

15% over the control. The significant increase was found in the height of plant (60 DAS) where rhizobium and phosphorus applied alone. Phosphorus application was found more effective for the increase in the height of plant at 60 DAS.

The increased growth of plant may be due to combined application of rhizobium, phosphorus and FYM. In fact, phosphorus play a critical role in the life-cycle of plants. It is important for the biological N-fixation, division of cells, in the formation of fats, in the transformation of starch to sugar and in every place of vital plant process. FYM application also increases the plant growth in the long duration crops. FYM corrects the physicochemical properties of soil and retains the macro and miocronutrients. The application of rhizobium inoculation significantly increased the growth of plant and other parameters. Rhizobium also increased the fixation of nitrogen in soil. These results are in agreement with the findings of Patel et al. (1991), Singh et al. (1993), Singh (1995) and Verma and Yadav (2001).

Table 4.I.1: Height of green gram 30 DAS (in cm)

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	17.0	17.8	17.8	17.6	17.5	17.8
30	18.0	17.6	17.3	18.0	18.1	18.2
60	17.4	17.9	17.7	17.9	18.2	18.4

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.27	NS	NS	0.38	NS	NS	NS

Table 4.1.2: Height of green gram 60 DAS (in cm)

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	38.2	38.4	38.3	41.3	41.0	41.5
30	40.8	41.5	41.0	41.0	43.9	44.0
60	42.0	41.8	41.6	44.3	44.0	44.3

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.35	NS	NS	0.49	NS	NS	NS

Grain and Straw Yield of Green Gram

The data recorded in the table 4.I.3 and 4.I.4 showed the effect of rhizobium inoculation along with phosphorus and FYM on the grain and straw yield of green gram. The maximum grain and straw yield was obtained in the treatment T_{17} (rhizobium inoculation + 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1}) to the extent of 12.26 and 25.62 q ha^{-1}, respectively. The maximum grain and straw yield increased up to 72.9 and 57 % over the control. Rhizobium inoculation alone significantly increased grain yield to the extent of 8.73 q ha^{-1} i.e. 23.1 % higher over control i. e. 7.09 q ha^{-1}. The combined application of rhizobium with increasing level of phosphorus from 30 to 60 kg P_2O_5 ha^{-1} increased the yield of straw to the extent of 24.91 and 25.60 q ha^{-1}, respectively. Grain yield significantly increased (9.76 and 11.02 q ha^{-1}) due to the increasing level of phosphorus up to 30 and 60-kg ha^{-1}, respectively to the extent of 37.6 and 55.4 percent over control sets. FYM alone did not give much effect on yield of grain, because FYM was observed more effective in long duration crops. The grain yield

significantly increased (11.02-q ha^{-1}) with the increasing level of phosphorus, but non-significant with increasing level of FYM (7.15 q ha^{-1}). The yield of straw significantly increased due to the application of rhizobia to the extent of 19.38 q ha^{-1}, recorded 19 % extra yield over control. The yield of straw increased from 20.49 to 23.59 q ha^{-1} with increasing level of phosphorus from 30 to 60 kg ha^{-1}, i. e. 25.7 & 44.6 % extra yield over control, respectively. FYM alone increased the yield of straw by 4.6 % over the control. The better response was observed due to the application of phosphorus individually or in combination with rhizobia.

These increases in yield of grain and straw were outcome from the application of rhizobia, phosphorus and FYM. Rhizobium inoculation can fix atmospheric nitrogen and increase the yield of crop. The bacteria penetrate the root hairs live in root nodules and co-operate with the higher plants and take the nitrogen from atmospheric air for the use and consumption for their own body and the crop also. When the bacteria are died, the nitrogen releases from their body and soil contain more N and enhance the growth and yield parameters of crop and soil nitrogen content. Phosphorus application improves the yield of grain and straw indicating its vital role in the life-cycle of the plant. FYM enhanced the crop yield through supplying sufficient organic carbon, micro and macronutrients. The observations are similar to the findings of Yadav et al. (1991), Prasad and Maurya (1992), Sharma et al. (1995), Selvi and Ramaswami (1995), Singh and Mishra (1998), Das et al. (1999), Singh et al. (2000), Yadav and Jakhar (2001), Verma and Yadav (2001) and Mani and Yadav (2002).

It may be concluded that the application of chemical fertilizer, biofertilizer and organic manure in an integrated manner increase the growth and yield of crops, enhance the nutrient status of soil and maintain soil health.

Table 4.I.3: Grain yield of green gram (in q ha^{-1})

P_2O_5 ($kg\ ha^{-1}$)	FYM ($t\ ha^{-1}$)					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	7.09	7.15	7.15	8.73	8.66	8.81
30	9.76	9.84	9.80	11.75	11.88	11.93
60	11.02	10.77	10.65	12.10	12.20	12.26

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.17	NS	NS	0.17	0.24	NS	NS

Table 4.I.4: Straw yield of green gram (in q ha^{-1})

P_2O_5 ($kg\ ha^{-1}$)	FYM ($t\ ha^{-1}$)					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	16.30	17.16	17.05	19.38	19.51	21.20
30	20.49	20.46	21.03	24.91	25.30	25.05
60	23.58	23.69	23.53	25.60	25.47	25.62

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	1.22	NS	NS	1.22	NS	NS	NS

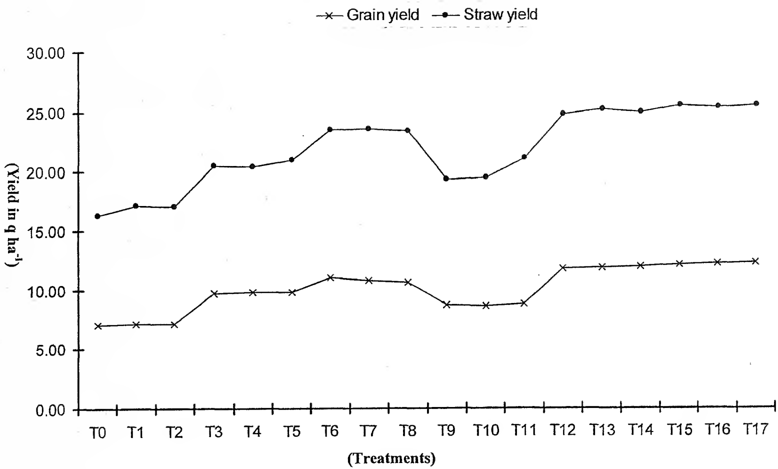

Figure 4.I.1: Effect of Rhizobium, Phosphorus and FYM on Grain and Straw yield of green gram

Nutrient content in green gram

Integrated use of bio fertilizer, organic and inorganic fertilizer is most effective in obtaining crop yield, maintaining soil fertility status and nutrient content in plant. The objective of the present investigation was to study the integrated effect of organic manure as well as biofertilizer along with chemical fertilizer to evaluate the nutrient content in plant. The results obtained during the study of "Integrated Nutrient Management with special reference to bio fertilizers" are as follows:

Total carbon content in green gram

It is obvious from the table 4.I.5 that various doses of FYM and the combined application of rhizobium, FYM and phosphorus have linearly increased the total carbon content in green gram. The individual effect of rhizobium and phosphorus has been observed non-significant. Similarly rhizobium + FYM, rhizobium + phosphorus and phosphorus + FYM have been observed non-significant also. The maximum carbon content of 28.36 % was obtained at the 60 kg P_2O_5 and 15 t FYM ha^{-1} applications, which were calculated 6.3 % higher over the control of 26.67 % in which no treatments were carried out. Application of FYM led to a greater accumulation of carbon content in plants. Soil organic matter and organic manures act not only as a source of nutrients but also influenced the carbon content in plant. Das et al. (1991), Singh (1999) and Dixit and Gupta (2000) have reported almost similar findings.

Table 4.I.5: Total carbon content (in %) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	26.67	27.36	28.06	28.15	27.87	28.01
30	26.96	27.66	26.96	27.65	27.53	28.18
60	27.53	27.59	28.36	27.32	28.06	28.08

Factor	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	NS	0.55	NS	NS	NS	NS	0.67

Total nitrogen content in green gram

The data presented in the table 4.I.6 indicates that the rhizobium, phosphorus and FYM have significantly and positively influenced the total nitrogen content in green gram. The double interaction of rhizobium + FYM and FYM + phosphorus have been observed non-significant. It is interesting to note that the double interaction of rhizobium + phosphorus and triple interaction of rhizobium + FYM + phosphorus have significantly and positively influenced the total nitrogen content of the plant. Rhizobium, phosphorus and FYM have individually increased the total N-content up to the extent of 2.29, 2.41 and 2.20 %, respectively. It was computed 8.5, 14.2 and 4.3 % higher over the control sets, respectively. The maximum N content (2.54%) was observed to treatment T_5 (30kg P_2O_5 + 15 t FYM ha^{-1}).

The above findings indicated synergistic relationship between P and N, FYM and N and rhizobium and N in nutrient content of plant.

Raut and Goniskar (1993) and Singh et al. (1990) have also reported increase in the N-accumulation by 37 % over control. Rhizobium inoculation increased the organic nitrogen content in plant, which may be due to increased nitrogenase activity during nodule formation. The similar findings have been reported by Maity et al. (1998). It clearly appears that N-content increased with the rate of P application and was observed higher with rhizobium inoculation. The results are in conformity with the findings of Jat et al. (1992), Khade et al. (1998), and Kwatra et al. (1999).

From the above findings it may be concluded that application of P increases N-content in green gram due to increased nodulation and the number of endomicorrhizal spores in the root zone of the legume crops. The findings also indicate the need for the addition of small amount of P to derive maximum benefit from inoculation with rhizobium. The results are in accordance with Manjunath et al. (1984).

Table 4.I.6: Total nitrogen content (in %) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	2.11	2.06	2.20	2.29	2.48	2.42
30	2.18	2.47	2.54	2.47	2.48	2.25
60	2.41	2.49	2.36	2.32	2.49	2.50

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.05	0.07	NS	0.05	0.07	NS	0.09

Total phosphorus content in green gram

It visualizes from the table 4.I.7 that various levels of treatment factor has significantly influenced the total P content in green gram. The uptake of P was observed the highest of 3590 ppm at treatment T_{13} that contains rhizobium inoculation along with 30 kg P_2O_5 ha^{-1} and 5 t FYM ha^{-1}. The individual effect of rhizobium, FYM and phosphorus and interaction between rhizobium + phosphorus and FYM + phosphorus was found significant. However, the interaction between rhizobium and FYM was observed non-significant. The combined effect of rhizobium, FYM and phosphorus gave 6 % extra uptake (3580 ppm) over the control (3390 ppm). The similar findings were obtained by Singh et al. (1990), Thind et al. (1990) and Raju et al. (1994).

The investigation suggests that the rhizobium inoculation in the presence of organic matter along with application of phosphorus improve the total P percentage in plant of green gram. Almost similar findings have been reported by Das et al. (1999).

Table 4.I.7: Total phosphorus content (in ppm) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	3390	3365	3400	3434	3480	3460
30	3500	3556	3499	3585	3590	3560
60	3492	3508	3520	3520	3545	3580

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	6.25	8.83	NS	6.25	8.83	8.83	10.82

Total potassium content in green gram

The data presented in the table 4.I.8 indicates that all the treatment factors significantly influenced the P-content except rhizobium + FYM interaction. The maximum accumulation of potassium (1.97 %) was observed at 30 kg P_2O_5 ha^{-1} and 15 t FYM ha^{-1} level, which was computed 28.75 % higher over the control (1.53 %). Total potassium content also existed synergistic relationship with all the treatment factors viz. R, F, P, R*P, F*P and R*F*P in green gram except R*F factor. However, higher K-status was recorded due to optimum P-supply to crop, which may be attributed to balanced fertilization. The combined effect of FYM and P was more prominent in uptake of K in green gram rather than their individual applications. The results are in conformity with the findings of Rao and Rao (1991), Das et al. (1999) and Kwatra et al. (1999).

It may be concluded that the application of rhizobium inoculation along with FYM and phosphorus application in an integrated manner increased the accumulation of N, P and K due to increased activity of rhizobacteria and enhanced N-fixation under the sufficiency of FYM and phosphorus. The similar results have been obtained by Singh et al. (1990).

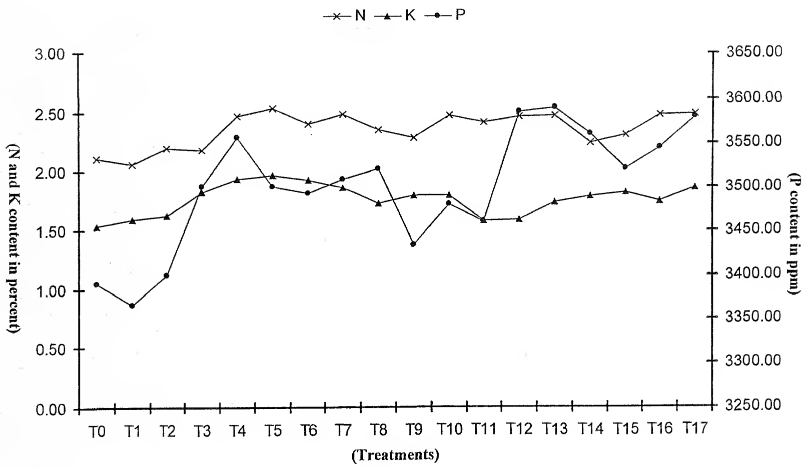

Figure 4.I.2: Effect of Rhizobium, Phosphorus and FYM on Total N, K and P content in green gram

Table 4.I.8: Total potassium content (in %) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	1.53	1.59	1.62	1.80	1.80	1.58
30	1.82	1.94	1.97	1.59	1.74	1.79
60	1.93	1.86	1.73	1.82	1.75	1.86

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.03	0.04	NS	0.03	0.04	0.04	0.04

Total zinc content in green gram

The data presented in the table 4.I.9 indicate that the different levels of treatment factors except R*F factor have significantly affected the total zinc content of green gram. The highest content of total zinc (194.8 ppm) was recorded at 30 kg P_2O_5 ha^{-1} along with rhizobium inoculated plots. It was computed 11% higher over the control sets (175.4 ppm). Though zinc and P interaction can immobilize the zinc, yet increased uptake can be explained due to higher content of Zn in the domestic wastes. Application of FYM significantly increased concentration of zinc in green gram plant due to the increased availability of zinc in soil. The observations are similar to the findings of Yadav et al. (1991) and Singh et al. (1999).

Plant uptake of Zn showed significant relationship with the application of rhizobium inoculation along with FYM and phosphorus. Dev (1997) observed the similar results also.

The results suggest that integrated use of chemical fertilizers with organic manure and biofertilizer on nutrient uptake specially of total Zn-content in green gram is essential.

Table 4.I.9: Total zinc content (in ppm) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	175.4	188.9	178.0	177.5	183.5	181.7
30	180.0	184.0	172.8	194.8	186.0	185.5
60	180.4	174.2	191.3	180.2	189.0	190.8

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	1.93	2.72	NS	1.93	2.72	2.72	3.34

Total copper content in green gram

The effect of integrated nutrient management on the total copper content in green gram plants were observed and results illustrated in table 4.I.10. All the treatments significantly increased the total Cu in plant over control. The concentration of total Cu was higher in treatment T_{10} (rhizobium inoculation + 5 t FYM ha^{-1}), treatment T_{12} (rhizobia + 30 kg P_2O_5 ha^{-1}), treatment T_{13} (rhizobia + 30 kg P_2O_5 ha^{-1} +5 t FYM ha^{-1}), treatment T_{15} (rhizobia + 60 kg P_2O_5 ha^{-1}) and T_{17} (rhizobia + 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1}) to the extent of 15.08, 15.02, 15.00, 15.10 and 15.02 ppm, respectively. The maximum Cu concentration in green gram was obtained in the

treatment T_{15} which contained rhizobia + 60 kg P_2O_5 ha^{-1} to the extent of 15.10 ppm, which was computed 9% higher over control sets (13.86 ppm). The total Cu content in plants significantly influenced due to rhizobium inoculation addition of FYM and phosphorus, individually except treatment T_1 (5 t FYM ha^{-1}). The Cu concentration in plant also significantly influenced due to the interaction of rhizobia + FYM, rhizobia + phosphorus, phosphorus + FYM and rhizobia + phosphorus + FYM except treatment T_8 (15 t FYM ha^{-1} + 60 kg P_2O_5 ha^{-1}).

These results suggest that the total Cu content in plants increased by the application of rhizobia, FYM and phosphorus. The increased total Cu content in plant may be possible due to the application of SSP and FYM, which are reported to contain variable amount of Cu, the normal range being 10-100 mg kg^{-1} for the SSP and 5-60 mg kg^{-1} for the FYM. These results are similar to Singh et al. (1999) and Saha et al. (1999).

It could be concluded that the application of chemical fertilizers, biofertilizers and organic manures in an integrated manner enhanced the productivity and maintained soil fertility. However, it was noted that the continuous use of phosphorus due to SSP and FYM may eventually lead to very high build up of available Fe, Cu and Mn in soil. Therefore, these nutrients are absorbed by plants in high concentration. Excessive amount of these elements will certainly create adverse nutritional problem and uptake of other elements and reduce the crop yield.

Table 4.I.10: Total copper content (in ppm) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	13.86	13.09	14.92	14.59	15.08	14.92
30	14.83	14.56	14.22	15.02	15.00	14.80
60	13.92	13.99	13.80	15.10	14.23	15.02

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.08	0.12	0.12	0.08	0.12	0.12	0.15

Total Iron content in green gram

The application of chemical fertilizers, biofertilizers and organic manures in an integrated manner on the total Fe content in green gram plant was observed and illustrated in table 4.I.11. All the treatments significantly increased the total Fe content in green gram plant over control. The maximum total Fe content (24.80 ppm) was observed in the treatment T_{10} (rhizobia + 5 t FYM ha^{-1}), which was computed 17.4% higher over control sets (21.12 ppm). The total Fe content in plants significantly influenced due to rhizobial inoculation and addition of FYM and phosphorus, individually. The concentration of total Fe in plants also influenced due to the interaction of rhizobia + FYM, rhizobia + phosphorus, phosphorus + FYM and rhizobia + phosphorus + FYM. These increments in total Fe content in plant may comes from the application of FYM, phosphorus and rhizobial activity. These findings are corroborated by Sachan (1994), Singh (1999) and Mukhopadhyay and Das (2001).

Table 4.I.11: Total Iron content (in ppm) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	21.12	21.72	24.40	24.00	24.80	24.23
30	24.68	23.30	23.90	23.91	23.59	23.86
60	22.92	22.99	24.00	24.10	24.26	23.92

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.20	0.28	0.28	0.20	0.28	0.28	0.35

Total Manganese content in green gram

The results obtained for total Mn content in green gram plants as affected by rhizobia, FYM and phosphorus are illustrated in table 4.I.12. The total Manganese content in plant significantly increased due to all the treatment factors. Concentration and uptake of Mn content in plants significantly increased due to rhizobia, FYM and phosphorus application individually. The interactive effect of rhizobia + FYM + phosphorus also observed positively significant. The maximum increase of total Mn content in plant (81.85 ppm) were obtained in the treatment T_{14} which contained rhizobia + 15 t FYM ha^{-1} + 30 kg P_2O_5 ha^{-1} which was computed 5.5% higher over the control sets (77.56 ppm). Singh et al. (1990) also reported that rhizobium increase P and Mn content in seed and straw both. The FYM and SSP which contain variable amounts of Mn in soil can increase the uptake of excessive total Mn content in plant (Singh et al., 1999 and Mukhopadhyay and Das, 2001).

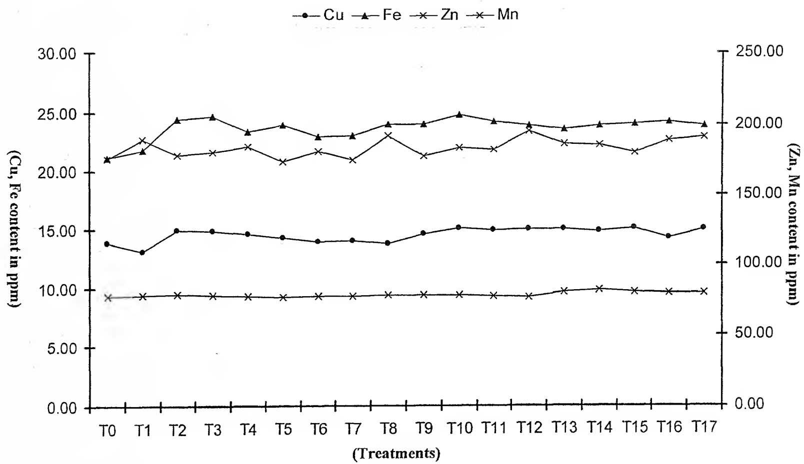

Figure 4.I.3: Effect of Rhizobium, Phosphorus and FYM on Total Zn, Cu, Fe and Mn content in green gram

The application of chemical fertilizers, biofertilizers and organic manures in an integrated manner enhanced the productivity and maintain soil fertility. FYM supply several macro and micronutrients to soil and plants and correct the physicochemical properties of soil, which sustain the crop productivity.

Table 4.I.12: Total Manganese content (in ppm) in plant samples of green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	77.56	78.29	79.02	78.40	78.50	77.50
30	78.40	77.90	76.99	77.00	80.29	81.85
60	77.56	77.89	78.20	80.40	79.87	79.92

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.29	0.41	0.41	0.29	0.41	0.41	0.50

Physicochemical properties of soil after harvesting green gram

Initial soil samples revealed no significant differences in the chemical properties studied. Therefore, it may be inferred that the initial soils were almost homogeneous in respect of pH, EC, Organic carbon, available N, P, K, Zn, Cu, Fe and Mn. The pH of initial soil samples ranges from 8.3 - 8.5, electrical conductivity ranges from 0.30-0.34 dSm^{-1} and O.C. ranges from 0.5-0.54%. The available N, P and K ranges from 166.3 - 170.3, 24.4-26.8 and 595-608 kg ha^{-1}, respectively. The available Zn, Cu, Fe and Mn ranges from 3.85-4.08, 5.24-5.37, 4.29-4.40 and 26.65-27.72 ppm, respectively.

Changes in pH status of soil

The data regarding pH status of soil have been presented in the table 4.I.13. The pH of soil samples showed a decreasing trend from initial to harvest for all the treatments. The decreases were more due to rhizobium inoculation. All the treatments gave greater considerable decrease in pH of soil in comparison to control. Phosphorus application significantly decreased the pH. The maximum and equal decrease was observed due to application of rhizobium + 60kg P_2O_5 ha^{-1} + FYM (15 t ha^{-1}) and 60kg P_2O_5 ha^{-1} + FYM (15 t ha^{-1}), respectively.

Trend of soil pH reduction at harvest over initial is common for all the treatments. In this experiment where the initial pH was more the greater reduction has been observed in the treatment which consist rhizobium, phosphorus and FYM. The application of phosphorus to the soil caused greater decrease in soil pH, which might be attributed to the presence of free sulphuric/phosphoric acid in the super-phosphate. Most of the prevalent cations such as Ca^{++}, Fe^{++} and Fe^{+++}, NH_4^+ etc. might have formed complex salts with PO_4^{---} ions, leaving H^+ ions to be the dominant ions in the soil solution and thus accounted for lowering of pH. Another possible reason for lowering of pH might be the excretion of organic acids by the roots of pulses and increased activity of microbes in the decomposition of sloughed off roots and thus producing different organic acid (Subba Rao, 1999). Rhizobium also produce organic acids, which decreased the pH of rhizosphere soil. Drop in pH of rhizosphere may be caused either by release of H^+ from roots or by low molecular weight of organic acids secreted by rhizosphere microorganisms. Almost similar results have been reported by Tamboli et al. (1999).

Table 4.I.13: pH level in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	8.4	8.3	8.3	8.3	8.2	8.1
30	8.3	8.2	8.1	8.2	8.1	8.0
60	8.2	8.1	8.0	8.1	8.0	7.9

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D.(0.05)	0.12	0.12	NS	0.17	NS	NS	NS

Changes in EC status of soil

Data presented in table 4.I.14 indicates that electrical conductivity of soil significantly increased with rhizobium, phosphorus and FYM alone. Electrical conductivity increases significantly with increasing level of phosphorus and increasing level of FYM. The maximum electrical conductivity was found due to the application of rhizobium + phosphorus (60kg P_2O_5 ha^{-1}) + FYM (15 t ha^{-1}) i.e. 0.46 dSm^{-1} to the extent of 35.2% over control i.e. 0.34 dSm^{-1}. All the inoculated treatments caused greater increase than control.

Seed inoculation of green gram with rhizobium alone or along with phosphorus and FYM resulted in increase of soil EC at harvest over the initial. Highly significant effect on the increase of EC was obtained with increasing level of phosphorus. Increasing level of FYM also increase the electrical conductivity over control. Almost similar results have been reported by Mallik and Sanoria (1980), Grewal et al. (1999) and Santhi et al. (1999).

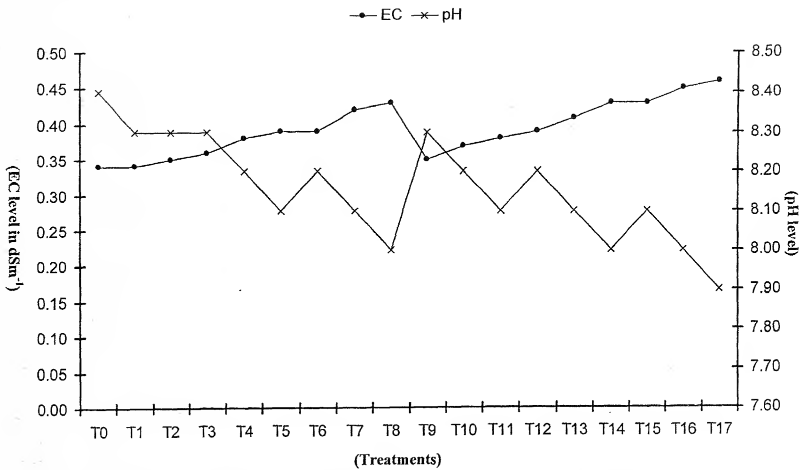

Figure 4.I.4: Effect of Rhizobium, Phosphorus and FYM on pH and EC level of soil under green gram.

Decrease in pH and increase in EC was positively and significantly correlated, thus showing a direct relationship on EC with pH. Therefore, the factors, which influenced soil pH also, influenced the EC of soil. Mineralization of nitrogen results in the formation of ammonium ions which replace other soil cations such as Ca^{++}, Mg^{++}, Na^{+} and H^{+} in the expanded lattice of clay minerals (Subba Rao, 1997). Thus an increment in the total soluble salts in the soil solution is expected. Further addition of 30-60 kg P_2O_5 ha^{-1} as superphosphate helped in the accumulation of particularly Ca^{++} in the soil.

Table 4.I.14: EC level (in dSm^{-1}) of soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	0.34	0.34	0.35	0.35	0.37	0.38
30	0.36	0.38	0.39	0.39	0.41	0.43
60	0.39	0.42	0.43	0.43	0.45	0.46

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	0.01	0.01	NS	0.02	NS	NS	NS

Changes in organic carbon status of soil

Organic carbon data are shown in table 4.I.15. Organic carbon of soil samples showed increasing trend at harvest over the initial samples except control and other treatments where FYM was not applied. Rhizobium significantly increased the organic carbon over control. The treatments, which contained FYM gave greater increase in

organic carbon percentage in soil than the control, because FYM supplied sufficient organic carbon to the soil. The maximum increase in organic carbon percentage was observed in the treatment T_{17} which consist rhizobium inoculation + phosphorus (60kg P_2O_5 ha^{-1}) + FYM (15 t ha^{-1}) i.e. 0.64% over control i.e. 0.52% to the extent of 23% higher over control. Combined use of bacterial cultures along with FYM showed greater increase of organic carbon than their corresponding single uses. Increase in organic carbon can easily be explained on account of root excretions and sloughed off root tissues and application of FYM. Ram and Sanoria (1979) reported increasing trend in soil organic carbon due to seed inoculation of peas.

Soil organic matter and added organic manure are not only a source of nutrient but also influences the availability of native nutrients. In the absence of fertilizers crop depend entirely on the mineralization of organically bound nutrients. The predominantly positive effect of soil organic carbon contents/manures on nutrient status and general fertility of soils was observed. Almost similar results has been widely revived and documented by Prasad and Singh (1987) and Grewal et al. (1999). The findings indicated that the organic carbon content increased with increasing amount of FYM application. It increased by 23% with the addition of 15 t ha^{-1} of FYM and 60 kg P_2O_5 ha^{-1} along with rhizobium inoculation. Almost similar findings have been reported by Kukreja et al. (1991) and Das et al. (1991).

Table 4.I.15: Percentage organic carbon in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	0.52	0.55	0.57	0.53	0.55	0.60
30	0.49	0.56	0.57	0.57	0.57	0.62
60	0.52	0.54	0.58	0.55	0.60	0.64

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	0.02	0.02	NS	NS	NS	NS	NS

Changes in available nitrogen status of soil

A perusal of table 4.I.16 clearly indicates that the available N content in soil increased with the application of rhizobium, phosphorus and FYM at various levels over the content of initial soil samples. Available N significantly increased with rhizobium alone or along with varying doses of phosphorus. Application of phosphorus, FYM and rhizobium increased the available nitrogen up to the maximum level (300.6 kg ha^{-1}) with phosphorus 60 kg ha^{-1} + FYM 5 t ha^{-1}+ rhizobium over the lowest level (166.3 kg ha^{-1}) in control, where no application of rhizobium, P & FYM was carried out. This increase was observed to the extent of 76.3%. Phosphorus alone up to the maximum level significantly increased the available N (198.5 kg ha^{-1}) over the control set, which was computed 19.4% higher over the control and along with FYM 15 t ha^{-1} to the level of 199.8 kg ha^{-1}, which was computed 20% higher over the control set. Rhizobium

alone significantly increased the available N by 43% whereas the increase was observed 44% higher along with the application of FYM 15 t ha^{-1} over the control. FYM alone increased the available N by only 5% but with the combination of rhizobium and phosphorus, it increased the available N status of soil to the extent of 76.3% over the control set.

Increase in soil nitrogen may be due to excretion of nitrogen from nodules. In general, application of additional dose of 30 to 60 kg P_2O_5 ha^{-1} caused greater increase in soil N. The best response in increasing the available N in soil was recorded in the treatment (T_{16}) which contained rhizobium + phosphorus (60 kg P_2O_5 ha^{-1}) + FYM 5 t ha^{-1} application. The increase in availability of N may be possible due to larger fixation of atmospheric-N by rhizobium in the presence of phosphorus and FYM. In fact, phosphorus enhanced the biological nitrogen fixation. The combined application of rhizobium, phosphorus 60 kg ha^{-1} and FYM 15 t ha^{-1} gave 46% extra available-N fixed in soil than their individual effects. FYM improved the soil physical environment by the way of improving soil structure, water holding capacity, soil aeration, moderating soil surface temperature which increase the activity of rhizobia in soil. The results are in conformity with the findings of von Uexkull and Mutert (1992), Tripathi and Mishra (2001) and Kulkarni et al. (1984).

These results suggest that integrated use of chemical fertilizer with organic manure and biofertlizers exerted beneficial effect on N-content in soil. The results are in conformity with the findings of Prasad and Rokima (1991), Toor et al. (1995) and Das et al. (1991).

Table 4.I.16: Available nitrogen (in kg ha^{-1}) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	166.3	170.0	174.6	237.8	229.0	240.0
30	196.7	187.0	198.0	262.0	275.2	260.7
60	198.5	201.4	199.8	291.5	300.6	298.1

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	5.07	NS	NS	7.18	7.18	NS	NS

Changes in available P status of soil

The data of available phosphorus presented in table 4.I.17 clearly indicates that various doses of phosphorus and FYM along with rhizobium significantly increased the availability of phosphorus in soil. The available phosphorus decreases in the control set from initial soil samples. FYM individually increased the available-P by 10.8% over the control set. Likewise, phosphorus significantly increased the available phosphorus to the extent of 52% at 30 kg P_2O_5 ha^{-1} application. The increasing level of phosphorus up to 60 kg P_2O_5 ha^{-1} increased the available-P content by two times over the control. The interaction of phosphorus and FYM increased the available P up to 46.3 kg ha^{-1} which was computed 92% higher over the control at 60 kg P_2O_5 and 15 t FYM ha^{-1} level. Application of rhizobium alone significantly increased the availability of phosphorus over the control set to the extent of 11.6%. The maximum available-P content was observed in the treatment (T_{15}), which contained rhizobium inoculation along with 60 kg P_2O_5 ha^{-1}. The combined application of 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1} gave 24% extra available-P content

over the control set. Similarly the combined application of rhizobium inoculation along with phosphorus and FYM gave 23.4% extra available P in the soil than their individual effects. The available-P content was observed same at both the level of FYM.

Takankhar et al. (1998) reported similar finding that seed inoculation and the application of nitrogen and phosphorus significantly increased the phosphorus in soil.

It may be concluded that utilization of 30 and 60 kg P_2O_5 ha^{-1} increases the P availability with increasing rate of phosphorus. The results obtained are in conformity with the findings of Hundal et al. (1988) and Thind et al. (1990). The phosphorus content in the soil was observed 24.0 kg ha^{-1} in control treatment and 48.5 kg ha^{-1} in the treatment receiving 5 t FYM and 60 kg P_2O_5 ha^{-1} along with rhizobium. Tomar and Sohanlal (1986) and Tomar (2000) have reported similar results.

Table 4.I.17: Available P (in kg ha^{-1}) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	24.0	26.6	26.3	26.8	24.2	27.1
30	36.5	33.0	34.7	40.9	44.0	41.0
60	48.2	43.0	46.3	51.0	48.5	48.2

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	1.28	NS	NS	1.81	1.81	NS	2.22

Changes in available k status of soil

The data of available K in soil have been presented in table 4.I.18. The available K of soil sample showed decreasing trend from initial to harvest for all treatments. The maximum decrease was observed in the treatment T_{15} that contained rhizobium inoculation with 60 kg P_2O_5 ha^{-1}. In fact, the application of increasing doses of FYM increase the available K in soil. Negative balance of available K was observed with increasing doses of phosphorus. Rhizobium caused significant decrease of available K in soil. Negative balance of K may be explained due to the fact that potassium addition was much less than the amount removed by crop. These results are in agreement with the findings of Yaduvanshi et al. (1984), Prasad and Rokima (1991), Kundu et al. (2000) and Mani and Yadav (2002).

It may be concluded that the amount of K added through the FYM was not sufficient for crop growth, hence available K decreased in soil from initial to harvest stage. The results suggest the need for higher rate of application of fertilizer potassium for crop cultivation.

Table 4.I.18: Available K (in kg ha^{-1}) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	595	588	597	573	580	588
30	570	576	581	560	577	583
60	557	568	572	541	570	576

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	6.52	6.52	9.22	9.22	NS	9.22	NS

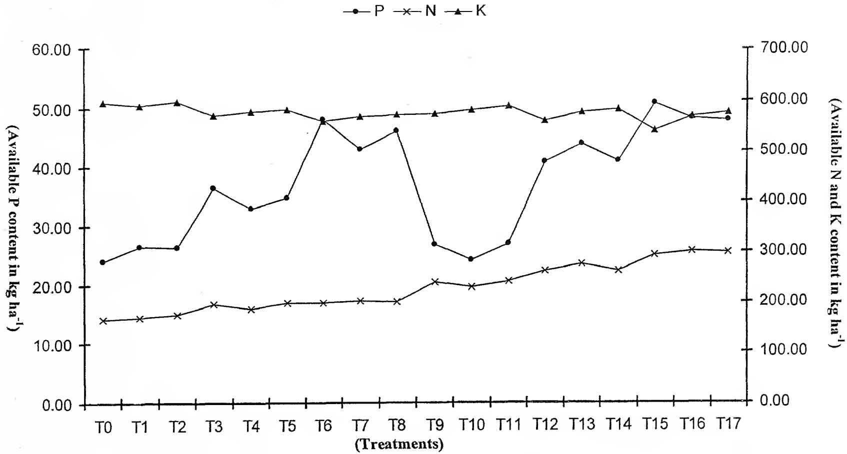

Figure 4.I.5: Effect of Rhizobium, Phosphorus and FYM on Available N, P and K content of soil under green gram

Changes in available Zn status of soil

After perusal of table 4.I.19 it appears that available Zn in soil decreased at all the treatments than the content of initial soil samples. Maximum decrease was found in the treatment T_3 that contained 30 kg P_2O_5 ha^{-1} than the initial soil samples. The application of increasing doses of FYM significantly and individually increased the available Zn in soil by 8% over the control set. The combined application of 15 t FYM and 30 kg P_2O_5 ha^{-1} significantly increased the available Zn in soil by 7% only. Thus application of phosphorus showed antagonistic relationship with the availability of Zn in soil. Rhizobium inoculation individually was observed significant and its combination with FYM and phosphorus caused maximum increase in the available-Zn in soil, up to the extent of 3.03 ppm vs. 2.75 ppm in control. Zinc availability in soil decreased at higher level of phosphorus (> 30 kg P_2O_5 ha^{-1}) application. Higher availability of zinc in soils is possibly due to presence of large amount of organic matter that had interfered the fixation of zinc in soil by forming chelates with Zn keeping in large fraction of the metal in available form. These exerted significant and adverse effect of high pH and the availability of zinc in soil. These findings are in accordance with Singh and Singh (1986), Kumar and Yadav (1995) and Santhi and Muthuvel (1995).

Table 4.I.19: Available Zn (in ppm) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	2.75	2.83	2.98	2.68	2.88	2.94
30	2.42	2.75	2.92	2.53	2.90	3.03
60	2.44	2.78	2.94	2.70	2.85	2.98

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	0.06	0.06	NS	0.08	NS	0.08	NS

Changes in available Cu status of soil

The data presented in table 4.I.20 obviously indicate that the available Cu in all the treatments decreased from initial soil samples. The decrease was found to the extent of 5-27 percent of their initial soil. The results showed that the amount of available Cu significantly increased with increasing level of FYM. Combined application of rhizobium, FYM and phosphorus significantly increased the availability of copper in soil to the extent of 5.10 ppm over the control i. e. 4.50 ppm. The maximum available Cu was observed in treatment T_2 (15 t FYM ha^{-1}), T_{14} (rhizobium + 15 t FYM ha^{-1} + 30kg P_2O_5 ha^{-1}) and T_{17} (rhizobium + 15 t FYM ha^{-1} + 60kg P_2O_5 ha^{-1}) to the extent of 5.10 ppm. High availability of Cu in these treatments was possibly due to presence of enough organic matter that had promoted the availability of Cu by supplying complexing agents that interfered with Cu fixation in the soil. These exhibited significant and antagonistic relationship between available Cu and pH in soil. Both rhizobium inoculation and phosphorus application did not show significant effect

on the availability of Cu in soil. Almost similar reports have been provided by Singh et al. (1986), Nambiar (1994) and Singh et al. (1999).

Table 4.I.20: Available Cu (in ppm) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	4.50	4.64	5.10	4.43	4.70	5.08
30	4.84	4.70	5.02	4.00	4.85	5.10
60	3.92	4.65	5.04	4.58	4.80	5.10

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	NS	0.09	NS	NS	0.14	NS	0.17

Changes in available Fe status of soil

It is obvious from the table 4.I.21 that various doses of FYM have significantly and positively affected the available Fe content in soil. However, rhizobium inoculation did not influence the content of available Fe in soil. The availability of Fe increased linearly from control set of 3.46 ppm to treatment T_2 of 3.92 ppm as the doses of FYM increased up to 15 t ha^{-1}. Available Fe in initial soil samples, on an average was observed 4.29 to 4.40 ppm and then it reduced to 3.46 ppm in control set where no application of any treatment was carried out. The amount of available iron (3.96 ppm) in soil was recorded to higher with the application of organic matter. The magnitude of such an increase, however, was more with the levels of organic matter indicating its synergistic relationship with the availability of iron in soil. The overall results indicate that the application of FYM,

phosphorus having significantly increased the availability of iron, whereas the application of organic matter to the soil relatively high in availability of iron in soil. Similar findings have been reported by Mukhopadhyay and Das (2001) that organic matter increased the amount of DTPA extractable Fe and Mn content of the soil. The above findings indicated antagonistic relationship of Fe with pH and $CaCO_3$ and significantly synergistic relationship with organic carbon which are in conformity with the findings of Vadivelu and Bandyopadhyay (1995) and Parmar et al. (1999).

It may be concluded that organic carbon, phosphorus and FYM is important factors in governing the available iron in soil.

Table 4.I.21: Available Fe (in ppm) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	3.46	3.70	3.92	3.50	3.69	3.80
30	3.59	3.81	3.90	3.48	3.84	3.92
60	3.50	3.85	3.96	3.53	3.80	3.95

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	NS	0.07	NS	0.10	NS	NS	NS

Changes in available Mn status of soil

The data presented in the table 4.I.22 indicate that the available-Mn content varied from control set of 23 ppm to 26.78 ppm in the treatment T_{17} which contained rhizobial inoculation along with 60 kg P_2O_5 ha^{-1} and 15 t FYM ha^{-1} application to the soils. The FYM significantly increased the available Mn up to the extent of 16.4

percent with the combination of phosphorus and rhizobium. The rhizobium, phosphorus and FYM alone and its interaction effect significantly increased the availability of Mn in soil except the interaction of rhizobium and FYM.

Rhizobium individually was observed beneficial for the availability of Mn, likewise phosphorus also produced similar results. Low iron and manganese content in soil is likely due to more alkaline (pH 8.1-8.4) nature of the experimental soils, because at higher pH, both Fe and Mn form insoluble hydroxides due to the oxidation of divalent cations to higher valent forms, which are relatively less soluble. The above results indicate antagonistic relationship of Mn with pH and synergistic relationship with organic carbon. Verma and Tripathi (1982), Parmar et al. (1999) and Mukhopadhyay and Das (2001) have confirmed almost similar results. It may be concluded that organic manures play vital role in the maintenance of soil fertility. Organic matter supplies macro and miocronutrients and humus substances to the soil and thereby to the plant.

Table 4.I.22: Available Mn (in ppm) in soil after harvesting green gram

P_2O_5 (kg ha^{-1})	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	5	15	0	5	15
0	23.00	24.00	26.45	23.25	25.17	26.30
30	23.40	25.43	26.68	23.10	24.98	26.72
60	23.36	25.00	26.00	23.45	26.05	26.78

Factors	R	F	R*F	P	R*P	F*P	R*F*P
C.D. (0.05)	0.23	0.23	NS	0.33	0.33	0.33	0.40

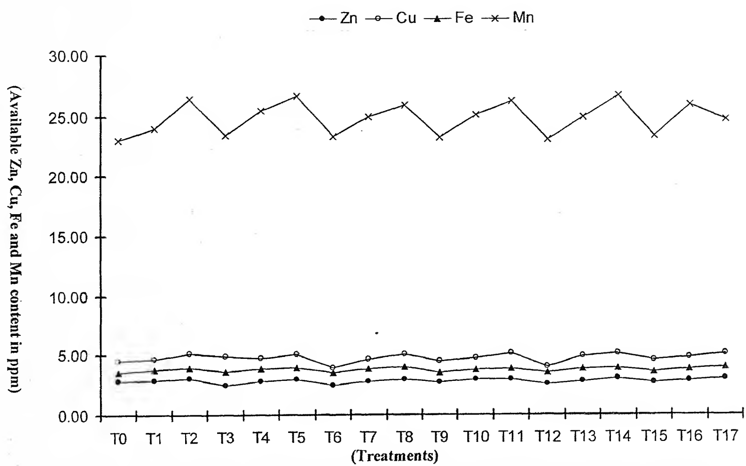

Figure 4.I.6: Effect of Rhizobium, Phosphorus and FYM on Available Zn, Cu, Fe and Mn content of soil under green gram

Experiment II

A field experiment was conducted with sandy clay loam soil in the winter season of 2001-02 to study the effect of rhizobium, NPK and FYM on soil and plant by Lentil (Lens esculenta) var. T-36. Rhizobium was applied by seed inoculation @ 250 g of culture per 10 kg seed, either alone or along with 3 levels of NPK, i.e. 0, 50 and 100 % and 3 levels of FYM, i.e. 0, 10 and 20 t ha^{-1} in eighteen different combinations. The results and findings obtained from experimental plot have been recorded in table 4.II.1 to 4.II.18 and discussed thoroughly are as follows:

In this investigation an attempt has been made to evaluate the cumulative effect of rhizobium, NPK and FYM on chemical properties of soil, yield of grain and straw and uptake of nutrient by lentil.

Growth and yield attributing characters of Lentil

The data pertaining to growth and yield attributing characters of lentil i.e. plant height 30, 60, 90, 120 days after sowing and yield of grain and straw has been summarized in table 4.II.1 to 4.II.6.

Height of lentil

The data pertaining to the height of plant 30, 60, 90 and 120 DAS is summarized in table 4.II.1 to 4.II.4, respectively. The height of plant 30 DAS was recorded in the table 4.II.1, observed non-significant over the control. The maximum height of plant (15.5 cm) was obtained with rhizobium inoculation + 50 % NPK application. All the treatments were found non-significant over control but little increase was observed in some treatment that was not much found

significant. The height of plant (15.4 cm) which was observed in the treatment T_7, T_8, T_{13} and T_{17} slightly increased over control (15.1 cm). The inoculation of rhizobium and application of other nutrients was found non-significant for the plant height (30 DAS) but some increment was found where chemical fertilizer was applied. Chemical fertilizers release nutrients easily and fastly but FYM release them slowly. So, FYM was observed more effective after long duration.

It is obvious from the table (4.II.2) that application of chemical fertilizer, biofertilizer and organic manure enhanced plant height 60 DAS significantly in comparison to control. The treatment T_{11}, which contained rhizobium inoculation along with FYM 20 t ha^{-1} gave higher shoot growth (28.0 cm) over the control (26.8 cm). Rhizobium significantly increased plant height (60 DAS) in the combination with NPK fertilizers. FYM also significantly increased the plant height along with NPK fertilizer to the extent of 27.6 cm.

Data presented in Table 4.II.3 indicates that the plant height (90 DAS) increased significantly with the application of rhizobium and NPK. Rhizobium alone significantly increased the plant height (36.6 cm) in comparison to control (35.8 cm). NPK alone significantly increased the plant height from 38.0 to 40.1 cm with its increasing level to the recommended doses. Treatment T_{15} gave higher increases in plant height (41.2 cm) over the control (35.8 cm). The minimum plant height was observed in the treatment To (control set). All the treatments showed impressive improvement, which contained chemical fertilizer alone or in combination with FYM and rhizobium. This increment in plant height may be due to the fact that chemical fertilizers supply macronutrients and FYM supplies both macro and micro nutrients, decrease pH levels and correct physical condition of soil. Rhizobium can fix atmospheric N in soil and thus plants take nitrogen for their own growth.

It is obvious from table 4.II.4 that the plant height 120 days after sowing was significantly increased with the application of chemical fertilizer, biofertilizer and organic manure. The highly significant value was recorded in the treatment T_{17} (rhizobium + FYM 20 t ha^{-1} + 100% NPK level) to the extent of 46.6 cm over the control (40.0 cm). The treatment T_{17} gave 16.5% more growth over the control. Thus, the combined effect of 100% NPK, FYM (20 t ha^{-1}) and rhizobium inoculation gave better response over all the treatments. A significant interaction was found between the NPK level and rhizobium inoculation, which increased the height of plant. Rhizobium inoculation brought significant improvement in plant height (120 DAS) to the extent of 5.75% over the control set. The higher response showed due to the NPK application in plant growth, in the conjunction of rhizobium inoculation. Almost similar findings were observed by the Singh et al. (1983), Singh (1985), Prasad and Maurya (1992), Patel et al. (1991) and Verma and Yadav (2001).

Table 4.II.1: Height of Lentil 30 DAS (in cm)

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	15.1	15.1	15.0	15.3	15.2	15.0
50 %	15.3	15.2	15.0	15.5	15.4	15.0
100 %	15.1	15.4	15.4	15.2	15.0	15.4

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	NS	NS	NS	NS

Table 4.II.2: Height of Lentil 60 DAS (in cm)

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	26.8	26.2	26.7	27.7	27.8	28.0
50 %	26.5	27.5	27.3	27.2	27.0	27.8
100 %	27.0	27.6	27.7	27.4	27.7	27.3

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.22	0.22	NS	0.32	0.32	0.32	0.39

Table 4.II.3: Height of Lentil 90 DAS (in cm)

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	35.8	36.6	36.6	36.6	36.7	37.0
50 %	38.0	37.8	38.2	41.0	40.9	40.7
100 %	40.1	40.1	40.3	41.2	40.8	40.0

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.31	NS	NS	0.44	0.44	NS	NS

Table 4.II.4: Height of Lentil 120 DAS (in cm)

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	40.0	41.0	40.3	42.3	43.0	43.4
50 %	43.0	44.0	43.7	45.7	46.0	46.2
100 %	44.4	44.9	45.2	46.0	46.4	46.6

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.31	0.31	NS	0.44	0.44	NS	NS

Grain and Straw yield of lentil

Data presented in table 4.II.5 and 4.II.6 indicate that the yield of grain and straw significantly increased with the application of rhizobium, chemical fertilizers and biofertlizers over the control. The maximum grain yield was obtained in the treatment T_{14} (rhizobium inoculation + 50% NPK + 20 t FYM ha^{-1}) and T_{17} (rhizobium + 100% NPK + 20 t FYM ha^{-1}) to the extent of 19.8 q ha^{-1}, which was 30.2% more over the control (15.2 q ha^{-1}). Where as maximum straw yield was obtained in the treatment T_{12} and T_{15} which contained rhizobium inoculation with 50 % NPK and 100% NPK to the extent of 41.2 q ha^{-1} more than 23.4 % over control. Rhizobium alone significantly increased the grain and straw yield i.e. 16.8 and 34.0 q ha^{-1}, respectively. The minimum straw yield (32.7 q ha^{-1}) was obtained in the treatment T_2 that consists 20 t FYM ha^{-1}. The minimum grain yield (15.2 q ha^{-1}) was recorded in the treatment T_0 (control). NPK

fertilizer application markedly increased the grain and straw yield of lentil over the control. The straw yield significantly increased due to the increasing level of the NPK alone or along with rhizobia and FYM except the treatment T_{12} and T_{15} where similar yield was obtained. The FYM application was found beneficial for straw yield. The grain yield significantly increased with the increasing level of NPK up to recommended doses alone or in conjunction with rhizobia and FYM except the treatment T_5 which contained 50 % NPK and 20 t FYM ha^{-1}. The findings of these treatments indicate that the maximum grain yield was obtained due to the combined application of rhizobium inoculation + 50% NPK + FYM (20 t ha^{-1}).

The optimum yield of lentil may be obtained by using rhizobium along with FYM and 50 % NPK. Therefore, NPK doses may be minimized up to 50 %. Thus, INMS helps in minimizing the cost of cultivation through use of biofertilizer and organic manure. Pareek (1985) Sinha and Mishra (1998), Subba Rao and Tilak (1984), Sinha and Mishra, 1998), Carrasco - Lopoz (1998) and Patel et al. (1986) observed the similar findings.

Application of increasing levels of NPK significantly increased the grain and straw yield. Rhizobium inoculation also improved the yield of grain and straw. Farmyard manure also showed beneficial effect on yield of grain and straw of the plant. But the combined application of NPK, rhizobium and FYM were found highly significant for the grain and straw yield over its individual application, since NPK is involved in cell division and cell elongation that increase plant growth. These results are in agreement with the findings of Kumar et al. (1988), Yadav et al. (1991), Prasad and Maurya (1992), Sharma et

al. (1995), Selvi and Ramaswami (1995), Toor et al. (1995), Bhatnagar and Chaplot (1996), Singh and Mishra (1998), Das et al. (1999), Kwatra et al. (1999), Namdeo and Gupta (1999), Singh et al. (2000), Mani and Yadav (2000), Verma and Yadav (2001) and Mani and Yadav (2002).

The overall effect of chemical fertilizer, biofertilizer and organic manure on growth and yield attributes has provided beneficial responses. In fact, FYM application improved the physical, chemical and biological properties of soil, which resulted in higher plant growth. Rhizobium inoculation can fix atmospheric nitrogen in soil and release several enzymes for plant growth. Hence, it may be concluded that the combined effect of rhizobia, NPK fertilizers and FYM were effective in improving up of grain and straw yield, plant growth, build up of nutrient status of soil, N-fixation and soil health.

Table 4.II.5: Grain yield of Lentil (in q ha^{-1})

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	15.2	15.8	15.8	16.8	17.1	17.3
50 %	17.4	17.8	17.6	18.8	19.5	19.8
100 %	18.0	18.4	18.7	19.0	19.7	19.8

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.27	0.27	NS	0.39	NS	NS	NS

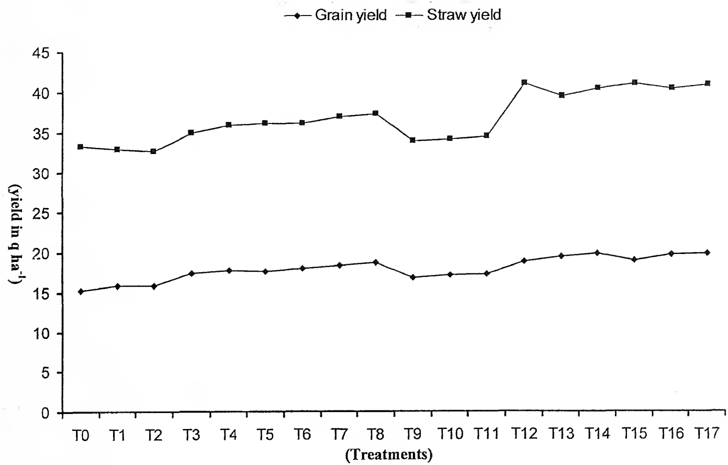

Figure 4.II.1: Effect of Rhizobium, NPK and FYM on Grain and Straw yield of Lentil

Table 4.II.6: Straw yield of Lentil (in q ha^{-1})

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	33.3	33.0	32.7	34.0	34.3	34.7
50 %	35.0	36.0	36.2	41.2	39.7	40.6
100 %	36.2	37.1	37.5	41.2	40.61	41.1

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.42	NS	0.59	0.59	0.59	NS	0.72

Nutrient content in lentil

Total carbon content in lentil

The total carbon composition in different plant samples under study (Table 4.II.7) revealed that FYM was the most dominant factor, which increased the total C content significantly. The highest carbon content of 28.36 percent was recorded at rhizobium inoculation along with 50% NPK and 10 t FYM ha^{-1} as against 28.06% in control set. Rhizobium inoculation and NPK application was observed non-significant, individually. The combined application of rhizobia, FYM and NPK significantly increased the total C content in lentil plants, whereas the interaction of other factor viz. rhizobium + NPK was observed non-significant. The total C content significantly enhanced with the application of FYM individually and its interaction with other factors.

The above findings clearly indicate that application of NPK through chemical fertilizers did not enhance the total organic C significantly, whereas application of these nutrients through organic matter (FYM) increases the total C content in plant samples of lentil significantly. .

The addition of FYM and rhizobium showed positive changes in organic C content of the plants. FYM supplied sufficient organic carbon status in soil, which enriched the primary, secondary and micronutrients in soil for plant growth. Das et al. (1991), Singh (1999) and Dixit and Gupta (2000) have obtained almost similar findings.

The above findings suggest that the application of rhizobia has a key role in crop yield sustainability. Integrated nutrients management evolves manures, bio-fertilizers and chemical fertilizers all are used together to achieve sustained crop production and maintained soil health.

Table 4.II.7: Total carbon content (in %) in plant samples of lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	28.06	26.60	27.32	26.99	27.53	27.59
50 %	27.36	26.67	28.06	26.60	28.36	28.15
100 %	26.96	28.25	27.66	26.87	28.01	27.65

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	0.31	0.31	NS	NS	0.31	0.38

Total nitrogen content in lentil

The application of rhizobium inoculation, FYM and chemical fertilizers in an integrated manner influence the total nitrogen content in lentil plants. The data are given in table 4.II.8. Rhizobium inoculation and NPK application, individually increased the total N content significantly, whereas the other combined treatments were observed non-significant. The maximum N content of 2.54% recorded at the application of 100% NPK and 10 t FYM ha^{-1} was computed 16.5 % higher than the control i.e. 2.18%. The minimum total N content was observed in the treatment T_2 (FYM 20 t ha^{-1}) to the extent of 2.06%. This might be due to the additional NPK and rhizobia which besides encouraging greater nodulation; perhaps prevented the losses of volatile ammonia from soil. The reason for increased N content and N uptake by lentil as the result of NPK fertilizers have been well explained and corroborate the findings of Singh et al. (1990), Chakarvorti and Chalam (1992), Bhardaj and Omanwar (1994), Dixit and Gupta (2000) and Das et al. (1999).

It may be concluded that the application of chemical fertilizer and biofertilizer is understood in view of its nitrogen fixing capacity, which enhanced the uptake of nitrogen, by plants and finally the crop yield.

Table 4.II.8: Total Nitrogen contents (in %) in plant samples of lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	2.18	2.11	2.06	2.38	2.10	2.40
50 %	2.23	2.37	2.28	2.36	2.49	2.48
100 %	2.47	2.54	2.41	2.42	2.47	2.48

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.09	NS	NS	0.09	NS	NS	NS

Total phosphorus content in lentil

The data presented in table 4.II.9 clearly indicates that the application of NPK, significantly increased the total P content linearly up to the level of 100% to the extent of 3540 ppm in treatment T_6. The maximum uptake of total P of 3585 ppm was observed in treatments T_{14} and T_{17} which contained rhizobium inoculation + 20 t FYM ha^{-1} with increasing level of NPK up to 100%. Rhizobium inoculation and FYM application alone or in combination was observed non-significant. The interactive effect of rhizobia + FYM + NPK was observed also non-significant. Increase in P content as a result of NPK fertilizers has also been reported by Shivananda et al. (1998), Dixit and Gupta (2000).

The observation of increased P content in plant as the result of NPK fertilization is self-explanatory and substantiates the findings of Takankhar et al. (1998). The P uptake value reveals that the inoculation to lentil plant in presence of NPK fertilizers, P is above

26.5 kg ha^{-1}. The above findings clearly indicate that the fertilizer application must be based on soil testing for different soil fertility classes.

Table 4.II.9: Total phosphorus content (in ppm) in plant samples of lentil

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	3335	3455	3360	3485	3390	3400
50 %	3520	3555	3500	3480	3545	3585
100 %	3540	3560	3520	3560	3520	3585

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	53.6	NS	NS	NS

Total Potassium content in lentil

The total K content under study (Table 4.II.10) revealed that NPK level was most dominant factor, which increased the total K content significantly. The maximum K content in plant samples to the level of 1.98% was observed in T_{17} treatments (rhizobium inoculation + 100% NPK + 20 t FYM ha^{-1}) and the lowest value of total K content (1.56%) was observed in treatment T_2 which contained FYM (20 t ha^{-1}). The application of rhizobium and FYM individually or in combination did not significantly influence the total K content of the lentil plant. The highest increase was observed in treatment T_{17} (rhizobia + FYM 20 t ha^{-1} + 100 % NPK) i.e. 21.5% higher over the control i.e. 1.63%. The application of NPK fertilizers significantly increased the total K content in plant due to the plants consumed the

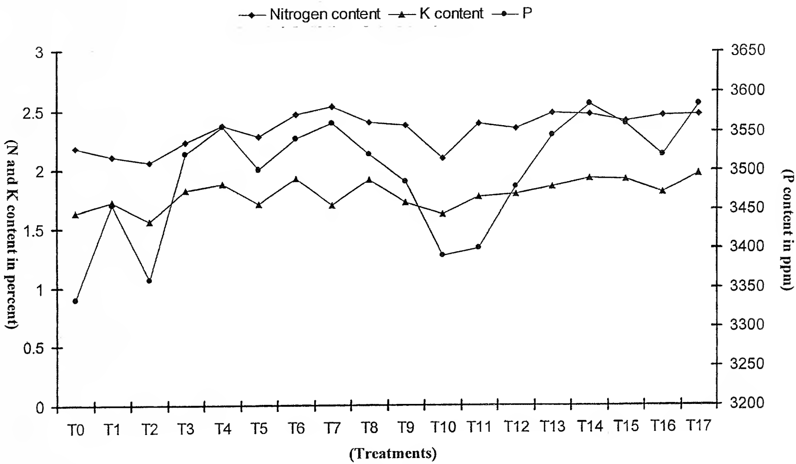

Figure 4.II.2: Effect of Rhizobium, NPK and FYM on Total N, P, K content in Lentil

excess amount of K as luxury consumption. Yadav et al. (1991), Nelson et al. (1997) and Dixit and Gupta (2000) have corroborated these findings.

However, higher K uptake was recorded due to the optimum NPK supply to crop, which may be attributed to balanced fertilization. The results are in conformity with those observed by Rao and Rao (1991) and Das et al. (1999) and Kwata et al. (1999).

It may be concluded that the amount of NPK added through chemical fertilizers increased the total K content in plant. The total K content increased because plants observed excess amount of K from soil. Hence it is suggested that potassium should be applied with the combination of organic manure and chemical fertilizers.

Table 4.II.10: Total potassium content (in %) in plant samples of lentil

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	1.63	1.72	1.56	1.72	1.62	1.77
50 %	1.82	1.88	1.81	1.80	1.86	1.94
100 %	1.93	1.70	1.92	1.93	1.81	1.98

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	0.14	NS	NS	NS

Total Zn content in lentil

The effect of integrated nutrient management on the total Zn content in plants have been illustrated in table 4.II.11. The results

showed that the application of rhizobium, FYM and NPK were observed non-significant in response to Zn accumulation in plants. Total Zn content in plant samples ranged from 173.8 to 197.0 ppm. The maximum Zn accumulation was obtained in the treatment T_2 (197.0 ppm) and T_{14} (197.0 ppm) and the minimum Zn accumulation was obtained in the treatment T_7 (173.8 ppm). The result indicates irregular distribution of total Zn content in plant samples, which may be ascribed due to application of high amount of domestic waste present in experimental soils. These findings have been corroborated by the Deb (1997) and Yadav et al. (1991). The additions of NPK fertilizers to soils have usually been made in the presence of FYM resulted in buildings up of reserves of P which interacted with Zn negatively and antagonistically up to their higher levels.

The above findings clearly indicate that the application of NPK, FYM and rhizobium either singly or in combination influenced the total content of Zn in plant antagonistically. Adsorption of Zn^{2+} on the hydrous oxides of iron [$(Fe_3(OH)_8$] and fixation of Zn with phosphate [$Zn_3(PO_4)_2$] has been suggested as the important mechanisms controlling Zn solubility in soils. Singh et al. (1999) and Bhattacharya et al. (2001) have reported similar findings.

Table 4.II.11: Total Zinc content (in ppm) in plant samples of Lentil

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	174.3	188.9	197.0	183.1	187.2	179.0
50 %	177.6	177.5	185.8	180.4	186.8	197.0
100 %	187.9	173.8	174.1	185.7	178.8	184.0

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	NS	NS	NS	NS

Total Cu content in lentil

The effect of integrated nutrient management on the total copper content in lentil plant was observed and results illustrated in Table 4.II.12. The application of NPK fertilizers significantly increased the total Cu content in plant to the extent of 15.10 ppm over control i.e. 14.96 ppm. The maximum increase in total Cu content of plant was observed in treatment T_3 which contained 50% NPK and minimum value was observed in treatment T_8 (100% NPK + 20 t FYM ha^{-1}) to the extent of 12.83 ppm. The combined application of rhizobium, FYM and NPK significantly decreased the Cu content in plant. The rhizobium and FYM was observed non-significant. The interactive effect of rhizobium + FYM, rhizobium + NPK and FYM + NPK were also obtained non-significant. The increased total Cu content in plant may be possible due to NPK and FYM, which have been reported to contain variable amount of Cu. These results are similar to Singh et al. (1999). In fact, excessive amount of these

elements will certainly create adverse nutritional problem and uptake of other elements and reduce the crop yield.

The uptake or concentration in plant tissue showed significant correlation due to application of NPK fertilizers and interaction of rhizobium, NPK and FYM. It could be concluded that the application of chemical fertilizer, biofertilizer and organic mannure in an integrated manner enhance the productivity and maintain soil fertility. These findings have been corroborated by Saha et al. (1999) and Singh et al. (1999).

Table 4.II.12: Total copper content (in ppm) in plant samples of Lentil

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	14.96	15.06	12.98	13.57	13.43	15.00
50 %	15.10	14.88	14.96	14.96	14.32	13.36
100 %	13.91	13.01	12.83	13.96	14.48	13.81

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	0.73	NS	NS	1.26

Total Iron content in Lentil

Data on total Fe content in lentil plants sample are furnished in table 4.II.13. Concentration of total Fe in plant were lowest (20.47 ppm) under treatment T_{11} (FYM 20 t ha^{-1} along with rhizobia) and highest (24.58 ppm) under treatment T_5 (50 % NPK + 20 t FYM ha^{-1}). The NPK fertilizers significantly increased the Fe content in plant.

Similarly, rhizobia + FYM and rhizobia + NPK also positively increased the total Fe content of plant. Individual effects of rhizobium and FYM were observed non-significant. The interactive effect of FYM + NPK and rhizobium + FYM + NPK application was obtained non-significant also.

The total Fe content increases due to the application of rhizobium, FYM and NPK and causes the reduction of higher oxides of Fe and Mn to soluble compounds. The similar findings have been obtained by Singh et al. (1999), Kundu et al. (2001) and Mukhopadhyay and Das (2001).

Table 4.II.13: Total Iron content (in ppm) in plant samples of Lentil

NPK level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	20.58	21.47	21.45	24.07	24.26	20.47
50 %	22.72	24.40	24.58	23.85	24.10	23.83
100 %	23.91	22.91	23.11	24.10	24.07	21.26

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	1.23	0.87	1.23	NS	NS

Total Mn content in lentil

The data presented in table 4.II.13 comprising different plant samples describe the irregular distribution of total Mn content in lentil. The Mn content, was observed to the extent of 76.99 ppm in the control set, whereas it was observed maximum of 80.93 ppm in the

treatment T_8 receiving 100 % NPK + 20 t FYM ha^{-1} application. The combined effect of 100 % NPK and 20 t FYM application gave 5 % extra uptake of Mn in plant samples over the control set. However the interaction effect among these treatment factors was observed non-significant. The increase in Mn content may be due to the reduction of higher oxides of Fe and Mn to soluble compounds. The results are in accordance with Singh et al. (1999). The treatments like FYM and NPK resulted in slight increase of tri-acid extractable Mn in the plant. A substantial amount of Mn also seems to have been contributed by FYM which contain variable amounts of this element. The results are in conformity with the findings of Singh et al. (1980).

It may be concluded that the decline in productivity with continuous and intensive cropping pattern leads to depletion in soil fertility in the imbalanced nutrient treatment. A balanced use of NPK and FYM may be successful in maintaining high level of nutrients in plant and maintaining soil fertility. However, it was noted that the continuous use of NPK and FYM may eventually lead to very high build up of available Fe, Cu and Mn in the soils. Excessive amounts of these elements will certainly create adverse nutritional problems and may prove to be antagonistic as for as absorption and uptake of other elements are concerned. Mukhopadhyay and Das (2001) have reported almost similar findings.

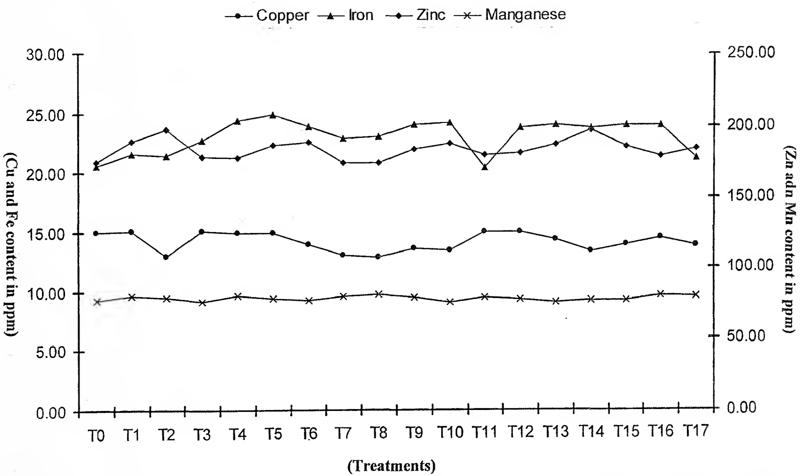

Figure 4.II.3: Effect of Rhizobium, NPK and FYM on Total Zn, Cu, Fe and Mn content in Lentil

Table 4.II.14: Total Manganese content (in ppm) in plant samples of Lentil

NPK Level	FYM ($t\ ha^{-1}$)					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	76.99	80.58	79.20	79.00	75.43	79.27
50 %	76.01	80.50	78.50	77.56	75.85	76.75
100 %	76.84	79.87	80.93	76.66	80.26	79.50

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	NS	NS	NS	NS	NS	NS

Physicochemical properties of soil after harvesting lentil

Changes in pH status of soil

The data presented in table 4.II.15 reveals that the pH of soil samples showed a decreasing trend at the various doses of FYM, NPK and rhizobium inoculation. The decrease was observed to larger extent due to rhizobium inoculation than the other treatments. Almost all the treatments produced marked decrease in the pH of soils over the control set.

The pH ranged from 7.6 to 8.1 with the treatments inoculated with rhizobium whereas the pH ranged from 7.7 to 8.3 in the other treatments. Increasing level of NPK up to recommended dose significantly decreased the soil pH. The combined application of 100 % NPK, 20 t FYM ha^{-1} and rhizobium inoculation caused maximum

decrease of soil pH. FYM alone significantly decreased the soil pH from 8.3 to 8.1, but (recommended dose) NPK decreased the soil pH from 8.3 to 7.7. Similarly rhizobium produced similar results as like to FYM in decreasing the soil pH. The decrease in soil pH may be ascribed as the application of FYM which produces organic acids. Another possible reason for lowering of pH may be the excretion of organic acids by the root pulses and the increased activity of microbes in the decomposition of sloughed off roots and then producing different acids in the soil. The application of NPK to the soil caused greater decrease in soil pH, which contained phosphorus as S.S.P., which may be attributed to the presence of sulphuric/phosphoric acid in the soil. Another reason for decrease in pH at harvest may be due to higher level of phosphorus application. It may be due to the fact that most of the trivalent cation such as cations Ca^{++}, Fe^{++} and NH_4^+ etc. have formed complex salts with phosphate (PO_4^{---}) ions, leaving H^+ to be the dominant ions in the soil solution and thus accounted for lowering of the pH. The results are in conformity with the findings of Tamboli et al. (1999) and Subba Rao (1999). The maximum reduction over its initial value of the pH was recorded in treatment T_{17} (rhizobium inoculation + 100 % NPK + 20 t FYM ha^{-1}). The higher reduction in soil pH in the plots receiving organic manures may be due to production of organic acids during the composition of organic manures, which neutralizes the Na^+ ions and increase the H^+ ion concentration. Das et al. (1991), Ghosh et al. (1995) and Datta et al. (2001) have reported almost similar results.

Table 4.II.15: pH level of soil after harvesting Lentil

NPK Level	FYM (t ha^{-1}					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	8.3	8.2	8.1	8.1	8.1	7.9
50%	8.1	8.0	7.9	7.9	7.8	7.7
100 %	7.9	7.8	7.7	7.8	7.7	7.6

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.17	NS	NS	0.24	NS	NS	NS

Changes in EC status of Soil

The value of electrical conductivity of soil is given in table 4.II.16. This table indicates significant increase in all treatments over control. Rhizobium alone significantly increased the electrical conductivity (0.36 dSm^{-1}) in comparison to control (0.32 dSm^{-1}). The combination of rhizobium with increasing level of NPK increased the electrical conductivity which was observed 56 % higher than the control. The treatment T_{17} that contained rhizobium, FYM (20 t ha^{-1}) and recommended dose of NPK was observed maximum increase than the other treatments. The electrical conductivity of treatment T_{17} was observed to the extent of 68.7 % (0.54 dSm^{-1} Vs. 0.32 dSm^{-1}) against the control. FYM alone also increase the electrical conductivity to the extent of 0.36 dSm^{-1} which was computed 12.5 % higher over the control. Mallik and Sanoria (1980), Snathy et al. (1999) and Grewal et al. (1999) have observed the similar findings. Highly significant effect on the increase of EC was obtained with increasing level of NPK and FYM over the control.

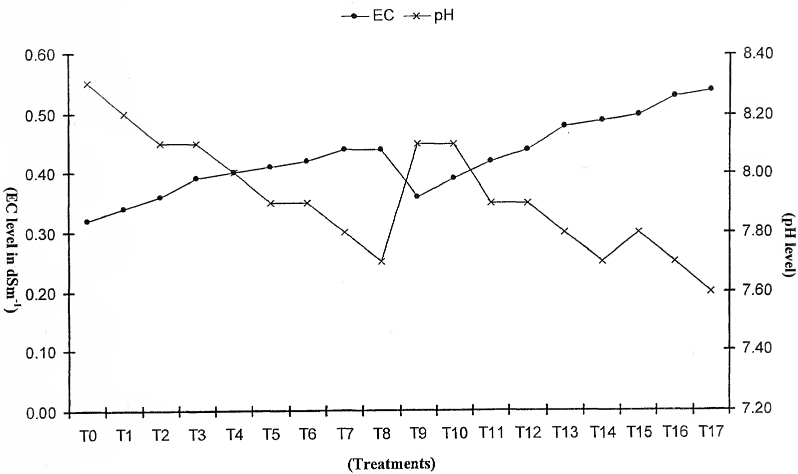

Figure 4.II.4: Effect of Rhizobium, NPK and FYM on pH and EC level of soil under Lentil

Decrease in pH and increase in electrical conductivity indicated antagonistic relationship, thus sowing a direct relationship of EC and pH. Therefore, the factors, which influenced soil pH also, influenced the EC of soil. Mineralization of nitrogen results in the formation of ammonium ions, which in the fixation process replace other soil cations such as Ca^{++}, Mg^{++}, Na^{+} and H^{+} in the expended lattice of clay minerals (Subba Rao, 1997). Thus an increment in the total soluble salt in the soil solution is expected. Further addition of NPK, which supplied by urea, supper phosphate and muriate of potash helped in the accumulation of particularly Ca^{++} in the soil. Mani and Yadav (2002) has evidenced similar results.

Table 4.II.2: EC level (in dSm^{-1}) of soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	0.32	0.34	0.36	0.36	0.39	0.42
50 %	0.39	0.40	0.41	0.44	0.48	0.49
100 %	0.42	0.44	0.44	0.50	0.53	0.54

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.02	0.02	NS	0.02	NS	NS	NS

Changes in organic carbon status of soil

It was observed (table 4.II.17) that the rhizobium inoculation significantly affected the organic carbon, because rhizobium inoculation can fix atmospheric nitrogen with the symbiosis of legume roots. After harvesting, legume root showed presence of rhizosperm

and decomposed by several microbes. Thus, organic carbon increased in soil. FYM alone or in combination of rhizobium and NPK significantly increased the organic carbon in soil to the extent of 45%. In the combination of FYM and rhizobium in different treatments the organic carbon increased from 7.8% to 18.8% against the control sets. Treatment T_{17} gave maximum increase of organic carbon in soil over control that was found 0.96 % Vs. 0.51 %. NPK alone was found non significant for the organic carbon, but NPK with the rhizobium inoculation caused lower increase in organic carbon content of the soil. The organic carbon in soil change did not for the addition of NPK.

In fact the addition of FYM helped in maintaining the organic carbon status of soil. However, it was noted that the continuous use of FYM might eventually lead to very high build-up of organic carbon. These results corroborated by Kukreja et al. (1991) and Singh et al. (1991). Increase in O.C. can easily be explained on account of root exertions and sloughed off root tissues and application of FYM.

Soil organic matter and added organic manures not only as a source of nutrient but also influence availability of native nutrients. In the absence of fertilizers crop depend entirely on the mineralization of organically bound nutrients. The predominantly positive effect of soil organic carbon contents/manures on nutrient status and general fertility of soils was observed. Almost similar results have been widely revived and documented by Prasad and Singh (1987) and Grewal et al. (1999). In fact organic matter retain the macro and micronutrients, it correct the aeration of soil, maintain soil physical condition, water holding capacity and decrease the soil pH and are beneficial for soil microbes (Mani and Yadav 2002). The organic matter release humic and fulvic acids. The highest concentration of humic acid formation might be possible under 100% NPK + FYM + rhizobium application could due to improved soil physical parameters and a conductive environment for the formation of complex organic molecules leading to

the formation of humic acid. The increase in organic carbon in soil with increasing levels of FYM followed a quadratic response and fertilizer use efficiency of FYM, when applied @ 10 and 20 t ha^{-1} FYM. The Santhy and Muthuvel (1995) observed the similar findings.

The maximum reduction was noticed in the control plot receiving neither chemical fertilizers nor organic manure, while maximum build up was measured in treatment T_{17} which contained rhizobium inoculation + 100% NPK + 20 t FYM ha^{-1}. It is evident from the table that the application of chemical fertilizer alone reduced the organic carbon content of the soil over its initial content, while significant buildup was observed in all those treatments where chemical fertilizers were applied along with organic manures and rhizobium inoculation. The organic carbon content of soil increased in treatments receiving FYM and depletion was noticed in treatment receiving chemical fertilizer alone. These results corroborate with the findings of Nambiar et al. (1989), Bisht (1990), Yadav et al. (2000) and Datta et al. (2001).

Table 4.II.17: Percentage OC of soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	0.51	0.60	0.74	0.54	0.67	0.84
50 %	0.52	0.62	0.76	0.55	0.70	0.91
100 %	0.51	0.65	0.74	0.57	0.72	0.96

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.03	0.03	0.04	0.04	NS	NS	NS

Changes in available nitrogen status of soil

The data presented in table 4.II.18 indicate that the application of rhizobium inoculation along with NPK and FYM significantly increased the availability of nitrogen. The available nitrogen increased with the increasing amounts of FYM. The data indicated that the percentage of available nitrogen varied from 158-320.8 kg ha^{-1} and rhizobium inoculation significantly increased the available-N over the control. The maximum available nitrogen (320.8 kg ha^{-1}) was observed in treatment T_{17} which contained 100% NPK, 20 t FYM ha^{-1} along with rhizobium inoculation, which was significantly superior over all the treatments during the year 2001-2002. Minimum available nitrogen (158.0 kg ha^{-1}) was noticed in the treatment T_0 (control sets) which reduced significantly over initial available nitrogen of the soil. The value of available nitrogen after harvesting of lentil crop under the treatments T_1 and T_2, which contained the various levels of FYM were observed 175.2 and 170 kg ha^{-1}, respectively. In the combination of 50% NPK and 10 and 20 t FYM ha^{-1} the value of treatment T_4 and T_5 is 200 and 198 kg ha^{-1}. The combined value of FYM 10 and 20 t ha^{-1} and 100 % NPK in the treatment T_7 and T_8 is 240 and 242.7 kg ha^{-1}, respectively. The available nitrogen was found 198 and 236.8 kg ha^{-1} in the treatment T_3 and T_6 which contained 50 % NPK and 100 % NPK, respectively. The rhizobium inoculation significantly increased the available nitrogen in soil over the control and initial value.

The value of available nitrogen (241.6 kg ha^{-1}) was observed in treatment T_9 (rhizobium alone) indicated that rhizobia can fix atmospheric nitrogen in the soil. The value of available nitrogen in treatment, which contained rhizobium inoculation alone or along with FYM and NPK significantly, increased over the uninoculated treatments. This increment in the available nitrogen was found from the nitrogen fixation properties of rhizobia. Rhizobium inoculation

increased the available-N (249.0 and 260.3 kg ha^{-1}) along with 10 and 20 t FYM ha^{-1} in the treatment T_{10} and T_{11}, respectively. The value of available nitrogen (280.0 and 307.9 kg ha^{-1}) was observed in the treatment T_{12} and T_{15}, which contained rhizobium inoculation in the combination of 50% and 100% NPK, respectively. The rhizobium inoculation significantly increased the available nitrogen in soil (290.0 and 294.6 kg ha^{-1}) in the combination of 10 and 20 t FYM ha^{-1} and 50% NPK, respectively. The status of available nitrogen in soil was observed in the treatment T_{16} (318 kg ha^{-1}) and T_{17} (320.8 kg ha^{-1}) which contained rhizobium inoculation along with 10 and 20 t FYM ha^{-1} and 100% NPK, respectively.

The availability of nitrogen in soil increased under the treatments having combination of rhizobia and chemical fertilizers form the nodules in root of pulse crops and fix the elemental nitrogen in its own body after harvesting the crop bacteria died and fixed nitrogen release in soil. In facts, FYM is helpful in the nitrogen fixation through the character of physical and chemical properties of soil, like soil aeration, pH, EC, water holding capacity and structure of soil. The supply of chemical fertilizer increased the availability of N and P content in soil. In fact, phosphorus plays a critical role in the life cycles of rhizobial bacteria and is important for biological nitrogen fixation. Tippannavar et al. (1990), Raju et al. (1991), Alvarez and Leon (1991), Toor et al. (1995) and Mani and Yadav (2002) also observed similar results. Phosphorus plays a key role since it is essential for the bacteria for the initial infection and nodulation of root system. For infection the cells must be in a mobile form and phosphorus has a pronounced effect on retention of this particular state. The similar finding was observed by the Sharma et al. (1987), Maurya and Sanoria (1986), Raut and Kohire (1991) and Ali et al. (2000).

Table 4.II.18: Available nitrogen (in kg ha^{-1}) in soil after harvesting lentil.

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	158.0	175.2	170.0	241.6	249.0	260.3
50 %	198.0	200.0	198.0	280.0	290.0	294.6
100 %	236.80	240.0	242.7	307.9	318.0	320.8

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	4.36	4.36	NS	6.17	NS	6.17	7.59

Changes in available phosphorus status of soil

Data regarding the effect of integrated nutrient management on available phosphorus status in soil has been presented in table 4.II.19. The highest available phosphorus (84.6kg ha^{-1}) was recorded under the treatment T_{17} which contained rhizobia + FYM (20 t ha^{-1}) + 100% NPK and minimum availability of P was observed in control sets (T_0). The availability of P significantly increases with increasing level of NPK alone up to 59 kg ha^{-1} Vs. 26.8 kg ha^{-1} (control set). Rhizobium alone increased the available P (29.9 kg ha^{-1}) but better response was found in the combination of FYM and NPK fertilizer. FYM alone was not found more effective in increasing available P concentration in soil but when it was used in conjunction of NPK and rhizobia, significant increase was observed over the control. The combined effect of NPK with FYM increased the availability of P up to 47.7 kg ha^{-1} (at 50 % NPK + 10t FYM ha^{-1}); 44.7 kg ha^{-1} (at 50 % NPK + 20 t FYM ha^{-1}); 60.8 kg ha^{-1} (at 100 % NPK + 10 t FYM ha^{-1}) and 62 kg ha^{-1} (at 100 % NPK + 20 t FYM ha^{-1}). The maximum response was obtained 60, 61.5, 78.5

and 84.6 kg ha^{-1} in the treatments T_{13}, T_{14}, T_{15}, T_{16} and T_{17}, respectively. Available P status of soil increased with increasing level of fertilizers and FYM. This could be lower utilization of P by crops from applied source, which resulted in building up of higher soil P status. The status of available P (84.6 kg ha^{-1}) was highest in the treatment receiving farm yard manure, chemical fertilizer and rhizobial inoculation. The less balance of available P was obtained in the treatment where fertilizer was not applied and also in the treatment of FYM alone or rhizobia alone. Prasad and Rokima (1991) and Biswas et al. (1999) obtained similar results.

Integrated use of chemical fertilizers, biofertlizers and FYM enhance the soil organic matter and available N,P and K status of the soil. Similar results were obtained by Nambiar and Ghosh (1984), Bharadwaj and Omanwar (1994), Sarkar et al. (1989), Prasad and Ram (1986), Khade et al. (1988), Upadhyay et al. (1991), Ishaq et al. (1994), Selvi and Ramaswami (1995), Toor et al. (1995) and Mani and Yadav (2000).

Table 4.II.19: Available phosphorus (in kg ha^{-1}) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	26.8	26.5	27.3	29.9	31.0	33.0
50 %	46.2	47.7	44.7	52.8	60.0	61.5
100 %	59.0	60.8	62.0	78.6	79.0	84.6

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	1.46	1.46	2.06	2.06	2.06	NS	NS

It may be concluded that the amount of N, P and K added through chemical fertilizer, organic manure and biofertilizer build-up the N and P status and its availability in soil. Application of organic manures resulted in tremendous rise in available P status of soil. The extremely high valued P might be attributed to the build up of available P owing to the application of organic manures and also formation of fulvic acids and others chelating agents which formed soluble complexes with native P in the soils. And other possibility is that higher pH (>7.6) might have decreased the possibilities of fixation or precipitation as insoluble Al Fe oxides or hydroxides. These results corroborate with the findings of Margrove and Thoams (1981) and Das et al. (1991).

Charges in available potassium status of soil

Effect of integrated use of organic, inorganic and biofertlizers on the available K in soil has been presented in table 4.II.20. The minimum available potassium was obtained in the treatment T_0 i.e. 580 kg ha^{-1} where neither chemical fertilizer nor the FYM and rhizobia were applied. The value of control set significantly decreased over its initial value. The FYM alone (573-581 kg ha^{-1}) was observed non significant over the control (580 kg ha^{-1}). In the combination of increasing level of NPK, FYM and rhizobium, available K significantly increased over the control because of NPK which supply sufficient potassium to the soil. The maximum available potassium (627 kg ha^{-1}) was observed in the treatment T_{17} which contained 100 % NPK + 20 t FYM ha^{-1} + rhizobium inoculation over the all treatments. The

available K significantly increased in the treatment T_8 which contained 100 % NPK + 20 t FYM ha^{-1} to the extent of 597 kg ha^{-1} over the control. Chemical fertilizer gave significant increase i.e. 584 kg ha^{-1} in the treatment T_3 but when its increased doses were applied the available K value increased to the extent of 591 kg ha^{-1}. The results are in conformity with the findings of Bhardwaj and Omanwar (1994), Nambiar (1994), Selvi and Ramaswami (1995) and Toor et al. (1995). The declining trend in the availability of potassium from initial to harvest occurred even under the crop removal of K was mostly heavy, whereas its external supplementation was much less. The increasing trend was observed in those treatments which contained NPK fertilizer. In which treatment that not contained NPK fertilizer, where available K was observed less than its initial value but it is higher from the first experiment, where K fertilizer was not used. In contrast to nitrogen and phosphorus, a negative balance of available K was obtained in the treatment, which contained no potassium fertilizer. Integrated use of fertilizer with organic manure and biofertilizer showed a negative balance of K in soil. Negative balance of K increased from 1 to 47 kg ha^{-1} with increasing dose of fertilizers and FYM, which can be substantiated, with increasing removal of K from soil by crops. The results already warned that if larger negative balance of K will not taken care of then soil K might turn into a serious yield limiting factor. These results are in agreement with the findings of Yaduvanshi et al. (1984), Kemmler (1987), Ghosh (1987), Prasad and Rokima (1991), Das et al. (1991) and Mani and Yadav (2002).

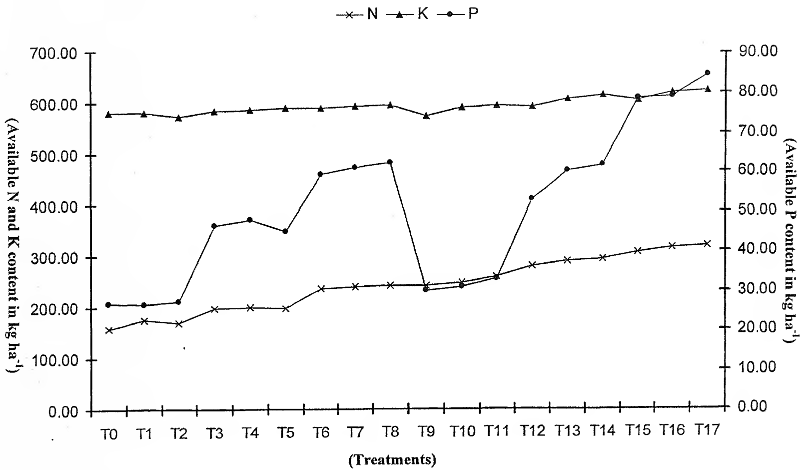

Figure 4.II.5: Effect of Rhizobium, NPK and FYM on Available N, P and K content in soil of under Lentil

Table 4.II.20: Available K (in kg ha^{-1}) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	580	581	573	575	593	596
50 %	584	587	590	595	609	618
100 %	591	595	597	608	623	627

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	13.72	NS	NS	19.40	NS	NS	NS

Changes in available Zn status of soil

The findings of available Zn were recorded in table 4.II.21. The observation showed that the declining trend was found in available Zn status of soil over its initial value from all treatments. The minimum value of available Zn (2.30 ppm) content was recorded in treatment T_6 which contained 100 % NPK alone. This lowest Zn content value was found because removal of Zn content to the plant was higher and no addition of Zn content was made in soil. It is evident from the data that the available Zn value under all the NPK levels alone or in combination with the rhizobium and FYM levels significantly decreased as compared to initial value of available Zn. In the respect of control set available Zn value significantly increased to the extent of 2.62 to 3.02 ppm except the treatment T_3 (2.4 ppm), T_6 (2.3 ppm) and T_{12} (2.5 ppm). Rhizobium inoculation brought significant improvement in available Zn to the extent of 2.63 ppm alone and in combination of FYM to the extent of 2.98 ppm in the treatment T_{11}. The beneficial

effect of increasing levels of FYM alone increased the availability of Zn to the extent of 2.8 and 2.9 ppm in the treatment T_1 and T_2, respectively. A significant interaction was observed between the increasing level of FYM and rhizobial inoculation. The maximum Zn availability (3.02 ppm) was observed in the treatment T_{17} which consisted FYM 20 t ha^{-1} + 100 % NPK + rhizobium inoculation. The observation showed that the available Zn concentration increased with the increasing level of FYM because organic manure contains micronutrients otherwise continuous cropping without fertilization would have depleted the soil of its native micronutrients status.

In fact, results emanating from 1NMS revealed that the application of rhizobia in combination with FYM increase the availability of Zn and other micronutrients status of soil. These findings have been corroborated by Bhardwaj and Omanwar (1994), Nambiar (1994), Kumar and Yadav (1995) and Siddhamalai et al. (1999).

Table 4.II.21: Available Zn (in ppm) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	2.57	2.80	2.90	2.63	2.93	2.98
50 %	2.40	2.62	2.92	2.50	2.90	2.99
100 %	2.30	2.72	2.88	2.67	2.85	3.02

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	0.06	0.06	NS	0.08	NS	NS	0.98

Changes in available Cu status of soil

The data on the available Cu in soil as affected by various treatments has been presented in table 4.II.22. It is evident from the table that the available Cu content reduced from its initial value. The minimum value of available-Cu was recorded in treatment T_{12} i.e. 3.92 ppm and maximum value was recorded in treatment T_{14} i.e. 5.10 ppm over control set i.e. 4.26 ppm. The maximum reduction of available Cu was found in the treatment T_{12} which contained rhizobium + 50 % NPK, whereas maximum value was observed in the treatment T_{14} which contained FYM 20 t ha^{-1} along with rhizobia and 50 % NPK. The similar value (5.10 ppm) was observed in the treatment T_8, T_{11} and T_{17}. FYM significantly increased the available Cu over the control. Whereas NPK level non-significantly increased the available Cu over control. Rhizobium inoculation gave significant improvement in the conjunction with NPK, whereas it was found non-significant alone. Availability of copper significantly increased with increasing level of FYM dose. Application of organic manures resulted in tremendous rise in available copper status of soil. It may be concluded that soil organic matter and added organic manures act not only as a source of nutrients but also influence availability of native nutrients. In the absence of fertilizers, crops depend entirely on the mineralization of organically bound nutrients. The integrated use of chemical fertilizers and FYM enhanced the soil organic matter and available N, P, K, Zn and Cu status of soil. Nambiar (1994), Bhardwaj and Omanwar (1994) and Siddhamalai et al. (1999) observed the similar findings.

Table 4.II.22: Available Cu (in ppm) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	4.36	4.70	4.98	4.30	4.95	5.10
50 %	4.40	4.82	5.08	3.92	4.86	5.13
100 %	4.31	4.80	5.10	4.60	4.96	5.10

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	0.94	NS	NS	0.13	NS	0.16

Changes in available iron status of soil

After the perusal of table 4.II.23, it can be noticed that the concentration of available Fe decreases from the initial value. The maximum value of available Fe was observed in treatment T_{14} that contained rhizobia + 20 t FYM ha^{-1} + 50 % NPK. There was a marked increase in the amount of available Fe due to the application of organic manures. The data indicate that the available Fe was greatly influenced by the application of 20 t FYM ha^{-1} along with 50 % NPK + rhizobial inoculation to the extent of 4.12 ppm over the control i.e. 3.42 ppm but its value is less that its initial value. So it is already warned that if larger negative balance of available Fe was not taken care of then soil might turn into serious yield limiting factor. The Bhardwaj and Omanwar (1994), Nambiar (1994) and Mukhopadhyay and Das (2001). In fact, the application of organic manure supplies several micronutrients to the soil. Organic carbon is a store house of nutrients. The availability of Fe significantly increases with the increasing level of FYM.

Table 4.II.23: Available Fe (in ppm) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	3.42	3.72	3.90	3.47	3.78	4.00
50 %	3.55	3.80	4.03	3.47	4.00	4.12
100 %	3.46	3.88	3.98	3.50	3.96	4.10

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	0.92	NS	0.13	NS	NS	NS

Changes in available Mn status of soil

The effect of different treatments on the changes in available Mn status of soil is shown in table 4.II.24. The highest reduction over its initial value was recorded in treatment T_{12} which contained rhizobium inoculation + 50 % NPK. These reductions in available Mn may be possible due to the some available Mn uptake by plant and no further addition of Mn occur in soil. The maximum available Mn was observed in the treatment T_{14} which contained 50 % NPK + 20t FYM ha^{-1} + rhizobial inoculation to the extent of 27.60 ppm over control i.e. 23.15ppm. The availability of Mn significantly increased with increasing levels of FYM up to 27.60 ppm but not affected by the increasing level of NPK. Rhizobium inoculation did not increase the available Mn i.e. 23.05 ppm over controls i.e. 23.15 ppm. FYM significantly increased the availability of Mn of soil. In fact, the available Mn increased from application of FYM because it supply some micro and macronutrients to the soil. Chemical fertilizer had no

significant effect on increase of available Mn in the soil. Almost similar findings have been observed by Bhardwaj and Omanwar (1994), Nambiar (1994), Parmar et al. (1999) and Mukhopadhyay and Das (2001).

Table 4.II.24: Available Mn (in ppm) in soil after harvesting lentil

NPK Level	FYM (t ha^{-1})					
	Without rhizobium			With rhizobium		
	0	10	20	0	10	20
0	23.15	26.27	27.50	23.05	26.85	27.55
50 %	23.04	25.80	27.04	23.00	26.49	27.60
100 %	23.12	25.61	27.43	23.26	26.46	27.50

Factors	R	F	R*F	NPK	R*NPK	F*NPK	R*F*NPK
CD.(0.05)	NS	1.48	NS	NS	NS	NS	NS

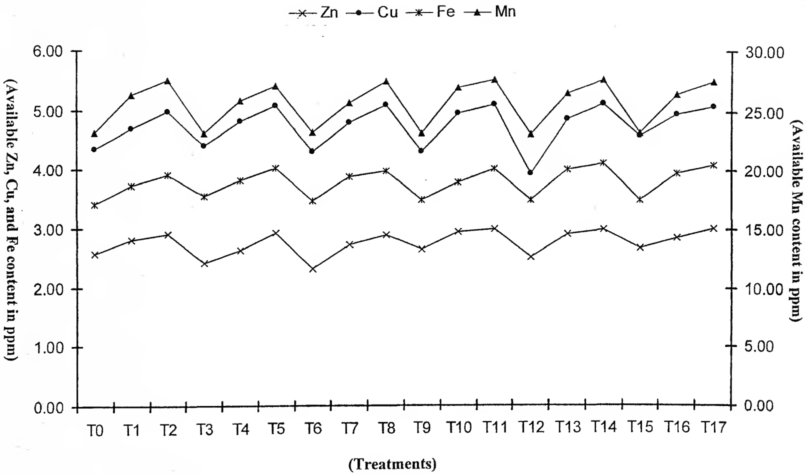

Figure 4.II.6: Effect of Rhizobium, NPK and FYM on Available Zn, Cu, Fe and Mn contents of soil under lentil

Chapter V

Summary and Conclusion

Summary and conclusion

Soils in India are not only 'thirsty' but also 'hungry'. Biodynamic system that makes significant use of organic matter and humus will help to improve soil structure and fertility. Integrated nutrient management system (IPNS) is an approach ecologically, socially and economically viable and environmentally unhazardous, at the same time sustaining soil productivity through optimization of all possible sources, both organic and inorganic.

The basic concept of the integrated nutrient management system is the maintenance of soil fertility and plant nutrient supply at the optimum level for sustaining crop productivity using all possible sources of plant nutrients in an integrated manner.

A field experiment entitled "studies on integrated nutrient management with special reference to bio-fertilizers", on growth and yield parameters, nutrient content in plants and nutrient status of soil was conducted during the year 2000-2002 at the Sheila Dhar Institute Experimental Farm, Allahabad. The green gram (Vigna radiata) cv. k-851 and Lentil (Lens esculenta) cv. T-36 were sown as the test crop.

The maximum plant growth of green gram was observed in treatment T_{15} (rhizobium + 60 kg P_2O_5 ha^{-1}) and treatment T_{17}(rhizobium + 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1})to the extent of 44.3 cm over control (38.2 cm), which was computed 16% higher over control. The maximum plant growth of lentil was observed in treatment T_{17} (rhizobium + 100% NPK + 20 t FYM ha^{-1}) to the extent of 46.6 cm over the control (40 cm), which was calculated 16.5 % higher growth over control. Phosphorus is needed in the division of cells, in the formation of fats, in the transformation of starch to sugar and in every place of vital plant process. In fact, FYM corrects the

physicochemical properties of soil and retains the macro and miocronutrients. The application of rhizobium inoculation significantly increased the growth of plant and other parameters.

The maximum grain and straw yield of green gram was obtained in the treatment T_{17} (rhizobium inoculation + 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1}) to the extent of 12.26 and 25.62 q ha^{-1}, respectively. The maximum grain and straw yield increased up to 72.9 and 57% over the control in green gram. Rhizobium inoculation alone significantly increased grain yield to the extent of 23.1 % i.e. 8.73 q ha^{-1} over control i. e. 7.09 q ha $^{-1}$. The combined application rhizobium and 30-60 kg phosphorus per hectare increased the yield of straw to the extent of 24.91 and 25.60 q ha^{-1}, respectively.

The maximum grain yield was obtained in the treatment T_{14} (rhizobium inoculation + 50% NPK + 20 t FYM ha^{-1}) and T_{17} (rhizobium + 100% NPK + 20 t FYM ha^{-1}) to the extent of 19.8 q ha^{-1}, which was 30.2% more over the control (15.2 q ha^{-1}). Where as maximum straw yield was obtained in the treatment T_{12} and T_{15} which contained rhizobium inoculation with 50 % NPK and 100% NPK to the extent of 41.2 q ha^{-1} more than 23.4 % over control.

The maximum carbon content in green gram (28.36%) was obtained at 60kg P_2O_5 ha^{-1}+15 t FYM ha^{-1} application which was calculated 6.3% higher over control (26.67%). The highest carbon content in lentil (28.36 percent) recorded at rhizobium inoculation along with 50% NPK and 10 t FYM ha^{-1} level as against 28.06% in control set. The combined application of rhizobia, FYM and NPK significantly increased the total C content in lentil plants.

Rhizobium, phosphorus and FYM have individually increased the total N-content in green gram to the extent of 2.29, 2.41 and 2.20 %, respectively. It was computed 8.5, 14.2 and 4.3 % higher over the

control sets, respectively. It clearly appears that N-content increased with the rate P application and was observed higher with rhizobium inoculation. The maximum total N content (2.54%) was observed in treatment T_5 (30kg P_2O_5 + 15 t FYM ha^{-1}). The maximum N content in lentil (2.54%) recorded at the application of 100% NPK and 10 t FYM ha^{-1} was computed 16.5% higher than the control i.e. 2.18%. The minimum total N content in lentil was observed in the treatment T_2 (FYM 20 t ha^{-1}) to the extent of 2.06%.

The total P content in green gram was observed the highest of 3590 ppm at treatment T_{13} that received rhizobium inoculation along with 30 kg P_2O_5 ha^{-1} and 5 t FYM ha^{-1}. The maximum total P content in lentil (3585 ppm) was observed in treatments T_{14} and T_{17} which contained rhizobium inoculation + 20 t FYM ha^{-1} with increasing level of NPK up to 100%.

The maximum accumulation of potassium (1.97 %) in green gram was observed at 30 kg P_2O_5 ha^{-1} and 15 t FYM ha^{-1} level, which computed 28.75 % higher over the control (1.53- %). Total potassium content also existed synergistic relationship with all the treatment factors viz. R, F, P, R*P, F*P and R*F*P in green gram except R*F factor. The maximum K content in plant samples of lentil (1.98%) was observed in treatment T_{17} (rhizobium inoculation + 100% NPK + 20 t FYM ha^{-1}) which was computed 21.5% higher over the control (1.63%). The application of NPK fertilizers significantly increased the total K content in plant due to the plants consumed the excess amount of K as luxury consumption.

The highest content of total zinc in green gram (194.8 ppm) was recorded at 30 kg P_2O_5 ha^{-1} along with rhizobium inoculated plots. It was computed 11 % higher over the control sets (175.4 ppm).The maximum Zn content in lentil were obtained in treatment T_2 and T_{14} i.e. 197 ppm and minimum Zn content were obtained in treatment T_7

(173.8 ppm). Though zinc and P interaction can immobilize the zinc, yet increase uptake can be explained due to higher content of Zn in the domestic wastes.

The total Cu content in green gram significantly increased by the application of rhizobia, FYM and phosphorus. The increased total Cu content in plant may be possible due to the SSP and FYM. The maximum Cu content in green gram was obtained in treatment T_{15} (rhizobia + 60 kg P_2O_5 ha^{-1}) to the extent of 15.10 ppm which was computed 9% higher over control (13.86 ppm). The total Cu content in lentil was observed maximum (15.10 ppm) in treatment T_3 (50 % NPK).

All the treatments significantly increased the total Fe content in green gram plant over control. The maximum total Fe content (24.80 ppm) was observed in the treatment T_{10} (rhizobia + 5 t FYM ha^{-1}), which was computed 17.4% higher over control sets (21.12 ppm). The concentration of total Fe in lentil significantly influenced due to the interaction of rhizobia + FYM, rhizobia + NPK. Concentration of total Fe in lentil were observed lowest (20.47 ppm) under treatment T_{11} (FYM 20 t ha^{-1} along with rhizobia) and highest (24.58 ppm) under treatment T_5 (50% NPK + 20 t FYM ha^{-1}).

The maximum increase of total Mn content in green gram (81.85 ppm) were obtained in the treatment T_{14} which contained rhizobia + 15 t FYM ha^{-1} + 30 kg P_2O_5 ha^{-1}, which was computed 5.5% higher over the control sets (77.56 ppm). All the treatment factors were observed significant over control. The Mn content in lentil was observed to the extent of 76.99 ppm in the control set, whereas it was observed maximum (80.93 ppm) in the treatment T_8 receiving 100% NPK + 20 t FYM ha^{-1} application. The combined effect of 100% NPK and 20 t FYM application gave 5% extra uptake of Mn in plant samples over the control set.

The combined application of 60 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1} + rhizobium inoculation and 100% NPK + 20 t FYM ha^{-1} + rhizobium inoculation causes maximum decrease in soil pH. The decrease in soil pH may be ascribed as the application of FYM produces organic acids. The application of phosphorus to the soil caused greater decrease in soil pH, which might be attributed to the presence of free sulphuric/phosphoric acid in the super-phosphate. It might be due to the fact that most of the prevalent cations such as Ca^{++}, Fe^{++} and Fe^{+++}, NH_4^+ etc. might have formed complex salts with PO_4^{---} ions, leaving H^+ ions to be the dominant ions in the soil solution. Another possible reason for lowering of pH might be the excretion of organic acids by the roots of pulses and increased the activity of microbes in the decomposition of sloughed off roots and thus producing different organic acid. Rhizobium also produced organic acids, which decreased the pH of rhizosphere soil.

Electrical conductivity increased significantly with increasing level of phosphorus and increasing level of FYM. Maximum increase in electrical conductivity was observed due to the application of rhizobium along with phosphorus (60kg P_2O_5 ha^{-1}) and FYM (15 t ha^{-1}) i.e. 0.46 dSm^{-1} to the extent of 35.2% over control i.e. 0.34 dSm^{-1}. All the inoculated treatments caused greater increase than control after harvesting green gram. The electrical conductivity of treatment T_{17} after harvesting lentil was observed to the extent of 68.7% (0.54 dSm^{-1} Vs. 0.32 dSm^{-1}) against the control. FYM alone also increase the electrical conductivity to the extent of 0.36 dSm^{-1} over the control i.e. 12.5%. Decrease in pH and increase in EC was positively and significantly correlated, thus showing a direct relationship on EC with pH. Therefore, the factors, which influenced soil pH also, influenced the EC of soil.

The maximum increase of organic carbon percentage in soil

under green gram was found in the treatment T_{17} which consist rhizobium inoculation + phosphorus (60kg P_2O_5 ha^{-1}) + FYM (15 t ha^{-1}) i.e. 0.64 %over control i.e. 0.52 %to the extent of 23%. Increase in organic carbon can easily be explained on account of root excretions and sloughed off root tissues and application of FYM. FYM alone or in combination of rhizobium and NPK significantly increase the organic carbon in soil to the extent of 45% higher over control. In the combination of FYM, rhizobium in different treatment varies from 7.8% to 18.8% against the control sets. Treatment T_{17} (rhizoibum inoculation + 100% NPK + 20 t FYM ha^{-1}) gave maximum increase of organic carbon in soil under lentil over control were found 0.96% Vs. 0.51%. NPK alone was found non-significant for the organic carbon.

Phosphorus alone significantly increased the available-N up to the maximum level (198.5 kg ha^{-1}) over the control set, which was computed 19.4% higher over the control and along with FYM 15 t ha^{-1} to the level of 199.8 kg ha^{-1} which was computed 20% higher over the control set. Rhizobium alone significantly increased the available N by 43% whereas the increase was observed 44% higher along with the application of FYM 15 t ha^{-1} over the control. Increase in soil nitrogen may be due to excretion of nitrogen from nodules. The best response in increasing the available-N in soil under green gram was recorded in the treatment (T_{17}) which contained rhizobium + phosphorus (60 kg P_2O_5 ha^{-1}) + FYM 15 t ha^{-1} application. The increase in available-N may be possible due to larger fixation of atmospheric-N by rhizobium in the presence of phosphorus and FYM. Rhizobium inoculation increased the available N in soil after harvesting lentil up to 249.0 and 260.3 kg ha^{-1} along with 10 and 20 t FYM ha^{-1} in the treatment T_{10} and T_{11}, respectively. The value of available nitrogen (280 and 307.9 kg ha^{-1}) was observed in the treatment T_{12} and T_{15}, which contained rhizobium inoculation in the combination of 50% and 100% NPK, respectively.

The status of available nitrogen in soil after harvesting lentil was observed in the treatment T_{16} (318 kg ha^{-1}) and T_{17} (320.8 kg ha^{-1}) which contained rhizobium inoculation along with 10 and 20 t FYM ha^{-1} and 100% NPK, respectively.

FYM individually increased the available-P significantly by 10.8% over the control set after harvesting green gram. Likewise, phosphorus significantly increased the available phosphorus to the extent of 52% at 30 kg P_2O_5 ha^{-1} application. The increasing level of phosphorus up to 60 kg P_2O_5 ha^{-1} increased the available-P content by two times more over the control. The interaction of phosphorus and FYM significantly increased the available P up to 46.3 kg ha^{-1} which was computed 92% higher over the control at 60 kg P_2O_5 and 15 t FYM ha^{-1} level. The maximum available-P content (51 kg ha^{-1}) was observed in the treatment (T_{15}), which contained rhizobium inoculation along with 60 kg P_2O_5 ha^{-1}. The highest available phosphorus in soil under lentil (84.6kg ha^{-1}) was recorded under the treatment T_{17} which contained rhizobia + FYM (20 t ha^{-1}) + 100% NPK. The availability of P significantly increase with increasing level of NPK alone up to 59 kg ha^{-1} Vs. 26.8kg ha^{-1} (control set). This could be lower utilization of P by crops from applied source, which resulted in building up of higher soil P status.

The available K of soil sample showed decrease trend from initial to harvest for all treatments. The application of increasing doses of FYM increases the available-K in soil. Negative balance of available K was observed with increasing doses of phosphorus. Negative balance of K may be explained due to the fact that potassium addition was much less than the amount removed by crop. The application of increasing doses of NPK either alone or along with rhizobia and FYM increased the available K in soil after harvesting lentil. This increment comes due to the application of K-fertilizer. The amount of K added

through the FYM was not sufficient for crop growth, hence available K decrease in soil from initial to harvest. Results suggested the need for higher rate of application of fertilizer potassium for crop cultivation.

The combined application of 15 t FYM ha^{-1} and 30 Kg P_2O_5 ha^{-1} significantly increased the available Zn in soil under green gram by 7% only. Application of phosphorus showed antagonistic relationship with the availability of Zn in soil. Zinc availability in soil decreased at higher level of phosphorus (> 30 kg P_2O_5 ha^{-1}) application. Rhizobium inoculation brought significant improvement in available Zn in soil under lentil crop to the extent of 2.63 ppm alone and in combination of FYM to the extent of 2.98 ppm in the treatment T_{11}. The maximum Zn availability (3.02 ppm) was observed in the treatment T_{17} which consisted FYM 20 t ha^{-1} + 100% NPK + rhizobium inoculation. Higher availability of zinc in soils is possibly due to presence of large amount of organic matter that had interfered the fixation of zinc in soil by forming chelates with Zn keeping in large fraction of the metal in available form. These existed significant and adverse effect of high pH to the availability of zinc in soil.

Combined application of rhizobium + 15 t FYM ha^{-1} + 60 kg P_2O_5 significantly increased the availability of Cu in soil under green gram to the extent of 5.10 ppm over the control (4.50 ppm). The similar results were obtained in the treatment T_2 and T_{14}. Maximum value of available Cu in soil under lentil was observed in the treatment T_{14} which contained FYM 20t ha^{-1} along with rhizobia and 50% NPK. High availability of Cu in treatments was possibly due to presence of enough organic matter that had promoted the availability of Cu by supplying complexing agents that interfered with Cu fixation in the soil.

The availability of Fe increased in soil of green gram linearly from control set of 3.46 ppm to treatment T_2 of 3.92 ppm as the doses

of FYM increased up to 15 t ha^{-1}. Available Fe in initial soil samples, on an average was observed 4.29 to 4.40 ppm and then it reduced to 3.46ppm in control set where no application of any treatment was carried out. The data indicate that the available Fe in soil of lentil was greatly influenced by the 20t FYM ha^{-1} along with 50% NPK + rhizobial inoculation to the extent of 4.12ppm rest over the control i.e. 3.42ppm but its value is less than its initial value. The higher amount of available iron in soil was recorded with the application of organic matter. The magnitude of such an increase, however, was more with the levels of organic matter indicating its synergistic relationship with the availability of iron in soil.

Rhizobium individually was observed beneficial for the availability of Mn; likewise phosphorus also produced similar results. The maximum available Mn was observed in treatment T_{17} in soil under green gram which contained rhizobia + 60 kg P_2O_5 ha^{-1} 15 t FYM to the extent of 26.78 ppm rest over control (23 ppm). The maximum available Mn in soil under lentil was observed in the treatment T_{14} which contained 50% NPK + 20t FYM ha^{-1} + rhizobial inoculation to the extent of 27.60ppm rest over control i.e. 23.15ppm. The availability of Mn significantly increased with increasing levels of FYM up to 27.60ppm but not affected by the increasing level of NPK. Low iron and manganese content in soil in likely due to more alkaline (pH 8.1-8.4) nature of the experimental soils, because at higher pH, both Fe and Mn form insoluble hydroxides due to the oxidation of divalent cations to higher valiant forms, which are relatively less soluble. The above results indicated antagonistic relationship of Mn with pH and $CaCO_3$ and synergistic relationship with organic carbon.

It may be concluded that the application of chemical fertilizers, bio-fertilizers and organic manures in an integrated manner enhanced the productivity, nutrient content in plants, nitrogen fixation in soil and maintain soil fertility.

Chapter VI

Bibliography

Bibliography

Ange, A.L. (1992). Environmental risks of fertilizer use, over use or misuse. *In Proc. Regional FADINAP seminar on fertilizers and Environment, Chiang Mai,* Thailand, 49 - 102.

Ali, Masood; Mishra, J.P. and Ali, M. (2000). Nutrient management in pulses and pulse based cropping systems. *Fertilizer News.* 45:4, 57-69.

Alvarez-Salis, J.D. and Leon-Martinez, N.S. (1991). Inoculation of phaseolus coccineus L. with Rhizobium leguminosarum by. Phaseoli strains under glasshouse conditions. *Tropical Agriculture.* 68: 3, 219-224.

Azad, A.S.; Gill, A.S. and Dhaliwal, H.S. (1991). Response of phosphorus and Rhizobium culture on grain yield of lentil. *Lens.* 18:1-2, 14-19.

Bachchan, S.M.; Jadhav, A.S.; Naidu, T.R.V. and Bachchhav, M.M. (1994), *J. Maharashtra Agric. Univ.,* **19**(2): 211-213.

Balasundaram, V.R. (1988): Performance of Rhizobium Japonicum strains tolerant to high temperature and low moisture. *Indian J. agric. Sci.* 58, 776-778.

Batra and Rao, D.L.N. (1985) *Indian J. Agrion.* **30**(3): 377-78.

Bhandal, B.K.; Gupta, R.P.; Pandher, M.S. and Khanna, V.C. (1989) *Acta Microbiologica Polonica,* **38** (2): 153-158.

Bhardwaj, V. & Omanwar, P.K. (1994) Long-term effects of continuous rotational cropping and fertilization on crop yields and soil properties. II. Effects on EC, pH, organic matter and available nutrients of soil. *J. Indian Soc. Soil Sci.,* **42,** 387-392.

Bhatnagar, G.S. and Chaplot. P.C. (1996). Long term studies on relative efficiency of legume and cereal based cropping systems. *Indian Journal of Pulses Research.* 9:1, 14-17.

Bhattacharya, P.; Ghosal, D.N. and Bhattacharya, S.K. (2001). Sorption and desorption of Zinc and Cobalt in different soils of West Bengal, soil clays and humic acids. *J. Indian. Soc. Soil. Sci.* 49:1, 85-89.

Bisht, P.S. (1990). Monitoring of changes in soil fertility, productivity and nutrient status of crops in rice based (rice - wheat). *Ph.D. thesis, G.B. Pant Univ. of Agric. and Tech.,* Pant Nagar, 171 pp.

Biswas, A.K.; Tomar, K.P. and Barman, K.K. (1999). Effect of pH and electrolyte on phosphate adsorption of some vertisol.

Bremer, E.; Kessel-C, Van; Nelson, L.; Rennie, R.J.; Rennie, D.A. and Van-Kessel, C. (1990). Selection of Rhizobium leguminosarum strains for lentil under growth room and field conditons. Plant and soil. 121:1, 47-56.

Burns, R.C. and Hardy, R.W.F. (1975) Nitrogen fixation in bacteria and higher plants. *Springer Verlag,* New York, U.S.A.

Carrasco- Lopoz, J.M. (1998) Effect of Bacterial inoculation and N fertilization in Cicer arietinum L. grown in the extremadura region. *3rd European conference on grain legumes. Opportunities for high quality, healthy and added-value crops to meet European demands. Valladolid,* Spain, 14-19 November, 416-417.

Chakarvorti, S.P. and Chalam, A.B. (1992). *Indian J. Agric. Sci.* 62, 535.

Chandra, R. (1985) *Legume Res.* **14**(3): 145-149.

Chandra, R. (1991). Influence of different levels of Rhizobium inoculum and phosphorus on nodulation, dry matter production and yield of lentil, *Legume Research,* 14:3, 145-149.

Chandra, R. and Pareek, R.P. (1985) *Tropical argic.* **62**(2): 90-94.

Chopra, S. L. and Kanwar J. S. (1991). Analytical Agricultural Chemistry. *Kalyani Publisher,* New Delhi.

Das, Madhumita; Singh, B.D.; Ram, Munna; Dwivedi, B.S. and Prasad, R.N. (1991). Influence of organic manures on native plant nutrient availability in an acid alfisol. *J. Indian Soc. Soil Sci.* 39; 286-291.

Das, P.K.; Sethi, A.K.; Jena, M.K. and Patra, R.K. (1999). Effect of P sources and Dual Inoculation of VA-Mycorrhiza and Rhizobium on Dry Matter Yield and Nutrient Uptake by Green Gram (Vigna radiata L.). *J. Indian Soc. Soil Sci.* 47:3, 466-470.

Daterao, S.H.; Lakhdive, B.A.; Hanwante, P.R. and Turkhede, A.B. (1990) *PKV Res. J.* 14(1): 75-77.

Datta, M.; Bhattacharya, B.K. and Saikh, H. (2001). Soil Fertility- A case study of shifting cultivation sites in Tripura *J. Indian. Soc. Soil Sci.* 49:1, 104-109.

Deb, D.L. (1997). Micronutrient Research and Crop Production in India. *J. Indian Soc. Soil Sci.* 45:4, 675-692.

Diener, T. (1950) Nutrition of legumes. *Butterworth Scientific Publication,* London, pp. 148.

Dingra, K..K. Sekhon, H.S. Sandhu, P.S. and Bhandari, S.C. (1988) *J. Agric. Sci.* 110(1): 141-144.

Dixit, K.G. and Gupta, B.R. (2000). Effect of FYM, Chemical and biofertilizers on yield and quality of rice and soil properties. *J. Indian. Soc. Soil Sci.* 48:4, 773-780.

Ghosh, A.B. (1987) Some aspects of stability in soil fertility and crop production. *J. Indian Soc. Soil Sci.* **35,** 552-567.

Ghosh, B.N.; Ved Prakash and Bhatnagar, V.K. (1995). Changes in soil properties and balance sheet of N, P and K under long term fertility management in soybean-wheat sequential cropping under rainfed conditions of U.P. Hills. *Indian Soc. Soil Sci.: 60th Annual Convention,* Nov. 2-5, 41-42.

Goswami, N.N. & Kamath, M.B. (1984) Fertilizer use researches on phosphorus in relation to its utilization by crops and cropping systems. *Fertil. News,* **29**(2), 22-26.

Grewal, K.S.; Singh, D.; Mehta, S.C. and Karwasra S.P.S. (1999). Effect of long-term fertilizer application on physicochemical properties of soil. *J. Indian Soc. Soil Sci.* 47:3, 538-541.

Gupta, B.R. and Sharma, A.K. (1989). *Farm Sci.* J.4 (1-2): 47-53.

Hameed, M.S. Murugesan, R. and Raj, S.A. (1988) *Madras Agric. J.* 75 (7-8): 281-82.

Ishac, Y.Z.; Angle, J.S.; El-Borollosy, M.A.; El-Demerdash, M.E.; Mostata, M.I. and Fares, C.N. (1994). Soil moisture inoculation and soil effect on growth and nodulation of Vicia faba and lens esculenta. *Annals Agril. Sci. Cario.* 39:2, 581-593.

Jackson, M.L. (1973) Soil Chemical Analysis. *Prentice Hall of India Pvt. Ltd.,* New Delhi.

Jagdish, Prasad; Ram, H. and Prasad J. (1996). Effect of zinc, copper and Rhizobium inoculation on their availability and uptake, and yield of green gram. *Agropedology*.6:75-78.

Jamwal, J.S.; Kalyan Singh; Singh, T.K. and Singh, J.P. (1989) *Annals agric. Res.*, 10(3): 249-252.

Jat, M.R. and Mali A.L. (1992) Effect of Phosphorus and seeding rate on physiological parameters and yield of Chickpea, *Indian J. Agronomy* 37:1, 189-190.

Kabi, M.C. and Behari (1990) *K. Indian Agriculturists*, 34(3): 163-167.

Kaur, R. (1991) *Annals, agric. Res.* 12(4): 288-393.

Kemi, P.N. and Gupta, A. (1991) *Res. Develop. Reporter*, 8(2): 176-179.

Kemmler, G. (1987) Soil Testing, Plant Analysis and Fertilizer Evaluation for Potassium. PRII, Gurgaon, p. 147.

Khade, V.N. and Patil, B.P.J. (1988) *J. Indian Soc. Coastal Agric. Res.* 6(2): 117-119.

Kothari, S.K. and Saraf, C.S. (1988) *J. Nucl. Agri. Biol.* 17(1): 34-38.

Kukreja, K.; Mishra, M.M.; Dhankar, S.S.; Kapoor, K.K. and Gupta, A.P. (1991). Effect of long term manurial application on microbial biomass. *J. Indian Soc. Soil Sci.* 39, 685-688.

Kulkarni, J.; Joshi, P.K. and Jojitra, V.K. (1984). Response of groundnut varieties to inoculation with rhizobia strain. *Indian J. agric. Sci.* 142, 515-519.

Kumar, A. and Yadav, D.S. (1995). Use of organic manure and fertilizer in rice - wheat cropping system for sustainability. *Indian. J. Agric. Sci.* 65:10, 703-707.

Kumar, A.; Malik, M.K. and Ahmad, N. (1988) *Lens News.,* 15(2): 24-27.

Kundu, D.K.; Neue, H.V. and Singh, R. (2000). Iron and Potassium availability to rice in Tropudalf and Sulfaquept as influenced by water regime. *J. Indian. Soc. Soil Sci.* 48:4, 130-135.

Kwatra, J.; Mishra, J.P. and Kwatra, J. (1999). Influence of planting pattern and fertilizers on yield and yield attributes and nutrient uptake in pea/mustard inter cropping system. *Indian J. Pulses Research.* 12:1, 38-43.

Lakshamanarao, K. and Kalyan Singh. (1983) *Madras Agric. J.* 70(9): 572-577.

Lindsay, W.L. and Norvell, W.A. (1978). *Soil Sci. Soc. Am. J.* 42, 421.

Maiti, S.; Das, C.C.; Chatterjee, B.N. and Sengupta, K. (1988) *Indian J. Agron,* 33(1) 92-94.

Mani, Dinesh and Yadav, Ved Prakash (2000). Mitigating soil pollution through Integrated Nutrient Management System. *Bioved* 11 (1, 2): 75-77.

Mani, Dinesh and Yadav, Ved Prakash (2002). Effect of biofertilizer along with phosphorus and FYM on yield of green gram (Vigna radiata L.) and N-fixation in soil. *University of Allahabad Studies (NMS).* 1:1, 35-37.

Manjunath et al. (1984). Response of Pigeon pea and cowpea to phosphorus and dual inoculation with rhizobium. *Topical Agric. (Trinidad)* 61, 48-52.

Milic, V.; Saric, Z.; Mrkovacki, N. and Vorosbnranyi, I. (1991). Bradyrhizobium japonicum capacity to synthesize growth regulators affecting nodulation and nitrogen uptake by soybean. *Mikrobiologija Beograd.* 1991, 28:2, 145-152.

Mukhopadhyay, D. and Das, D.K. (2001). Effect of organic matter, Lime and Zinc application on the availability of Iron and Magnanese in acid soils under submergence. *J. Indian. Soc. Soil Sci.* 41:1, 80-84.

Nambair, K.K.M. & Ghosh, A.B. (1984) Highlights of Research of a Long Term Fertilizer Experiment in India (1971-82). *LTFE. Res. Bull.* **1.**, IARI, New Delhi.

Nambiar, K.K.M. & Abrol, I.P. (1989) Long term fertilizer experiments in India- An overview. *Fertil. News,* **34**(4), 11-20.

Nambiar, K.K.M. (1994) *Soil Fertility and Crop Productivity under Long-Term Fertilizer Use in India.* ICAR, New Delhi.

Nambiar, K.M.M. and Arbal, I.P. (1989). Long term fertilizers experiments in India (1971-82) *LTFE Res. Bull. P.* 101, IARI, New Delhi.

Namdeo, S.L. and Gupta, S.C. (1999). Efficacy of biofertilizers with different level of chemical fertilizer on pigeon pea (Cajanus cajan L.). *Crop Research Hisar.* 18:1, 29-33.

Parmar, D.K.; Sharma, V.; Sharma, K.D. and Sharma, T.R. (1999). Micronutrient status of vegetable growing pockets in cold desert area of Himachal Pradesh. *J. Indian Soc. Soil Sci.* 49:2, 280-283.

Patel, K.S.; Thakkar, N.P.; Chaudhari, S.M. and Shah, R.M. (1986). *Int. Chickpea News.*, 14:22-24

Patel, R.S. and Patel, Z.G. (1991) Effect of FYM, N, P and rhizobium inoculation on the growth and yield of gram (Cicer arietinum L.). *Annals-of-Agricultural-Research.* 12:2, 200-202.

Patnaik, S. Panda, D. & Dash, R.N. (1989) Long term fertilizer experiments with wetland rice. *Fertil. News,* **34**(4), 47-52.

Pedgaonkar, S.M. and Raut, K.G. (1985) *Intl. Chickpea Newsl.*, 13:26-27.

Piper, C.S. (1960). Soil and Plant Analysis. *Inter Science Publisher,* New York.

Prasad, B. (1994) Integrated nutrient management for sustainable agriculture. *Fertil. News,* **39**(9), 19-25.

Prasad, B. and Rokima, J. (1991). Integrated nutrient management-I. Nitrogen fractions and their availability in calcareous soil. *J. Indian Soc. Soil Sci.* 39, 783-785.

Prasad, J. and Ram H. (1986) *J. Indian Soc. Soil Sci.,* 34: 762-766.

Prasad, J. and Ram, H. (1982) *Legume Res.* 5(1): 42-44.

Prasad, J. and Ram. H. (1988) *Legume Res.* 11(2): 66-70.

Prasad, J. and Sanoria, C.L. (1981) Response of Bengal gram to seed bacterization and phosphorus *Seeds-and-Farms.* 7:4, 31-32.

Prasad, J. and Sanoria, C.L. (1984) *Legume Res.* 7(1) 13-16.

Prasad, R.N. and Maurya, A.N. (1992). Note on effect of rhizobium at different levels of P_2O_5 an growth, nodulation and yield of garden pea cv. Arkel. 21:3-4, 208-212.

Rai, R. (1988) *J. Pl. Nutri.,* 11:6-11, 863-869.

Rai, R. (1992) *Biol. Fertl. Soils,* 14(4): 293-99.

Rai, R.N. and Ange, A.L. (1991). Integrated plant nutrition system (IPNS) and sustainable agriculture. *Proc. FAI Annual Seminar FAI,* New Delhi, p. SV/1-1-SV/1-12.

Raju, M.S. and Varma, S.C. (1984) Response of Bengal gram (Cicer arietinum L.) varieties to Phosphate fertilization in relation to FYM application on Rhizobial inoculation. *Legume- Research,* 7:1, 23-26.

Raju, M.S.; Varma, S.C. and Ramaiah, N.V. (1991) Effect of Phosphorus in relation to FYM Vs. Rhizobium inoculation on nutrient uptake by chickpea cultivars under rainfed condition. *Indian-Journal-of-Agricultural-Research.* 25:1, 43-48.

Rao, S. and Rao, A.S. (1999). Impact of Farmyard Manure and Phosphorus Application on Soil Potassium Status and K uptake in a Vertisol under Soybean-Wheat system. *J. Indian Soc. Soil Sci.* 47:1, 176-178.

Rathore, R.S.; Singh, P.P.; Khandwe, R. and Khandwe, N. (1992), *P.P. Lens Newsl.,* 19(1): 32-35.

Raut, R.S. and Kohire, O.D. (1991) *Legume Res.* 14(2): 78-82.

Raut, R.S. and Kohire, O.D. (1991) Phosphorus response in chickpea (Cicer arietinum L.) with Rhizobium inoculation. *Legume-Research,* 14:2, 78-82.

Reddy. M.G.; Ghosh, B.C. and Sudhakar, N. (1994) *Indian J. Agri. Res.,* 28(1): 60-64.

Rewari, R.B. (1988a). Summarised results of microbiology trials conducted during kharif 1987. *Workshop of All India Coordinated Project on Improvement of Pulses (ICAR),* Udaipur, India.

Rewari, R.B. (1988b). Summarised results of microbiology trials conducted during Rabi, 1987. *Workshop of All India Coordinated Project on Improvement of Pulses (ICAR),* Akola, India.

Rickerl, D.H. et al. (1981). The effects of P on growth and N content of winter legumes grown on acid soil. Agron-abstre. *Ann. Meeting Am. Soc-Agron.* 189 (En).

Roy, R.K. and Singh, B.K. (1989) *Intl. Chickpea News.* 21, Dec.: 27-28.

Sachan, R.S. (1994). *Indian Farmers Digst.* 27, 9.

Saha, J.K.; Mandal, B.; Mete, P.K. and Adhikari, T.K. (1999). Extractability of copper in Alfisols in relation to plant tissue concentration. *J. Indian. Soc. Soil Sci.* 41:3, 519-525.

Santhi, R.; Selva Kumari, G. and Perumal Rani (1999). Soil Test based Fertilizer Recommendations under Integrated Plant Nutrition System for Rice-Rice-Pulse Cropping Sequence. *J. Indian Soc. Soil Sci.* 47:2, 288-294.

Santhy, P. and Muthuvel, P. (1995). Studies and soil organic matter under long term fertilizer experiment. *Indian Soc. Soil. Sci.: 60th Annual Convention,* Nov. 2 - 5, 45-44.

Santhy, P.; Velusamy, M.S.; Murugappan, V. and Selvi, D. (1999). Effect of Inorganic Fertilizers and Fertilizer-Manure Combination on Soil Physicochemical Properties and Dynamics of Microbial Biomass in an Inceptisol. *J. Indian Soc. Soil Sci.* 47:3, 479-482.

Sarkar, A.K. (2000). Integrated nutrient management for better livelihood of farmers in rainfed areas. *J. Indian Soc. Soil Sci.* 48:4, 690-696.

Sarkar, A.K.; Mathur, B.S., Lal,; S. & Singh K.P. (1989) Long term effects in sub-humid laterite soils. *Fertil. News,* **34**(4), 71-80.

Sarkar, B.B.; Bhattacharjee, N.R. and Roy. S. (1989) *Indian Emg.,* 38(12): 13-14.

Sarkar, M.C. and Rattan R.K. (1995). Integrated Nutrient Management for sustainable agriculture. *Proceedings of a Training cum seminar on Soil Nutrient Management, IARI,* New Delhi, 62-74.

Senaratne, R. and Ratnasinghe, D.S. (1995). Nitrogen fixation and beneficial effects of some grain legumes and green manure crops on rice. *Biology and Fertility of Soils.* 19:1, 49-54.

Sharma, J.P. et al. (1984). Efficiency of rhizobial inoculation under P fertilization. *J. Indian Soc. Soil-Sci.,* 32, 494-500.

Sharma, R.D.; Pareek, R.D. and Chandra, R. (1995). Residual effect of phosphate and rhizobium inoculation in chickpea on succeeding maize and fodder sorghum. *J. Indian Soc. Soil Sci.* 43:4, 600-603.

Sharma, S.P. (1995). Soil environment and crop yields as influenced by long term application of fertilizers. *Indian Soc. Soil Sci.: 60th Annual convention,* Nov. 2-5, 93-94.

Sharma, U.C. (1991). Response of potato to phosphorus and FYM and Acid soils of Khasi hills of Meghalaya. *J. Indian Soc. Soil Sci.* 39: 387-387.

Shivananda, T.N.; Sreerangappa, K.G.; Lalitha, B.S.; Parama, V.R.R. and Siddaramappa, R. (1998). Dynamics of nitrogen, phosphorus, potassium and sulphur in frenchbean as influenced by source of nitrogen application. *Indian Journal of Pulses Research.* 11:2, 56-60.

Siddhamalai et al. (1999). Distribution of DTPA - extractable zinc, copper, iron, manganese contents in some rice soils of Tamil Nadu, *J. Indian Soc. Soil Sci.* 47:3, 553-555.

Singh G.B. (1999). Natural Resource Management for Sustainable Agricultural Production. *J. Indian Soc. Soil Sci.,* **47**:1, 1-8.

Singh G.R.; Chaure, N.K. and Parihar S.S. (2001). Organic farming for sustainable agriculture. *Indian Farming.* June- 2001, 12-14.

Singh M.V. (1997). 27th Progress Report of AICRP micro and Secondary nutrients and Pollutant Elements in soil and plants, 1-118.

Singh R.B. (1995). Soil Nutrient Management for sustainable agriculture development. *Proceedings of a training cum seminar on Soil Nutrient Management, IARI,* New Delhi, 1-7.

Singh, A.K.; Khan, S.K. and Nongkynrih, P. (1999). Transformation of Zinc in wetland rice soils in relation to nutrition of rice crop. *J. Indian. Soc. Soil. Sci.* 42:2, 248-253.

Singh, A.K.; Ram, H. and Maurya, B.R. (1999). Effect of nitrogen and phosphorus on microbial population, growth and nodulation of green gram. *J. Indian Soc. Soil Sci.* 47:1, 159-161.

Singh, A.K.; Singh, N.B. and Singh, S.B. (1987) *Intl. Chickpea News.* 17:36.

Singh, B. and Kumari, M. (1990) *Legume Res.,* 13(3): 139-145.

Singh, G. (1985). Study on the effect of phosphorus levels on growth and yield of summer cowpea. *Indian-Journal-of- Agricultural-Research,* 19(3) 138-142.

Singh, K.K. and Mishra, J.P. (1998). Biofertilizer in pulses. *Fertilizer News.* 43:12, 91-94.

Singh, Kalyan; Rao, K.L.; Jamwal, J.S.; Bohra, J.S. and Singh, K. (1983). Effect of phosphorus and biofertilizers on growth yield and quality chickpea (Cicer arietinum L.). *Transactions-of-Indian-Society-of-Desert. Technology-and –University-Centre-of-Desert-Studies.* 8:1, 33-38.

Singh, L. (1987). Experimental Agricultural Chemistry and Soil Sci. *Bhargava and Co.,* Alld., 333.

Singh, M.; Barman, K.K.; Kundu, S. and Tripathi, A.K. (1999). Transformation of soil organic pools of N as influenced by integrated use of organic manure and fertilizer nitrogen under soyabean wheat system in vertisal. *J. Indian. Soc. Soil Sci.* 47:3, 483-487.

Singh, M.V. (1991). Micronutrient management in rice-wheat Cropping System. *Project Directorate for Cropping System Research,* Modi Puram, 133.

Singh, N.P.; Sachan, R.S.; Pandey, P.C. and Bisht (1999). Effect of a decade long-term fertilizer and manure application on soil fertility and productivity of rice - wheat system in Mollisal. *J. Indian. Soc. Soil Sci.* 41:1, 77-80.

Singh, P.K. and Bisoyi, R.N. (1993). Biofertilizers for restoration of soil fertility. *Restoration of degraded land: concepts and strategies* 25-47.

Singh, S.C. and Yadav, D.S. (1985). Response of Chickpea (Cicer arietinum L.) varieties to Phosphorus levels and seeding rates. *Indian Journal of Agronomy.* 30:4, 414-416.

Singh, S.P. and Verma R.P.S. (1984). Agricultural Statistics. *Rama Publishing House,* Baraut, Merrut.

Sinha, S.K. (1977) FAO Plant Production and Protection, *paper,* 3 AGPC Misc. 36.

Subba Rao, N.S. (1999) Soil Microbiology. *Oxford & IBH Publishing Co. Pvt. Ltd.*, New Delhi.

Subba Rao, N.S. and Tilak, K.V.B.R. (1984) In: Pulses Production-Constraints and Opportunities. *Oxford and IBH Publishing Co. pp.* 331-340.

Takankhar, V.G.; Mane, S.S.; Kamble, B.G. and Suryawanshi, A.P. (1998). Phosphorus uptake at different stages and yield attributes of gram crop as affected by P and N fertilization and Rhizobium inoculation. *Journal of Soils and Crops.* 8:1, 53-57.

Takkar, P.N. & Nayyar, V.K. (1981) Preliminary field observation of manganese deficiency in wheat and berseem. *Fertil. News,* **26**(2), 22-23, 33.

Tamboli, B.D.; Daftardar, S.Y. and Shinde, B.N. (1999). Effect of legume cropping on soil reaction at soil root interface. *J. Indian Soc. Soil. Sci.* 47:1, 141-143.

Thind, S.S.; Rishi, A.K. and Goswami, N.N. (1990). Utilization of applied of applied P by green gram (Vigna radiata L.), Bengal gram (Cicer arietinum L.) and cowpea (Vigna unguiculata L.) in soils of Delhi. *Journal of Nuclear Agriculture and Biology.* 19:3, 152-156.

Tilak, K.V.B.R. (1995). Biofertilizers- Their use and management. *Proceedings of a Training-cum-Seminar on Soil Nutrient Management, IARI,* New Delhi, 25-33.

Tippannavar, C.M.; Rajashekara, E. and Sreenivasa, M.N. (1990). Effects of FYM extract on Rhizobium sp. And Azotobacter chroococcum strains. *Journal of Maharashtra Agricultural Universities.* 15:2, 237-238.

Tisdale, S.L.; Nelson, W.L.; Beaton, J.D. and Havlin, J.L. (1997) Soil Fertility and Fertilizer (fifth edition). *Prentice Hall of India Pvt. Ltd.*, New Delhi.

Tiwari, K.N. (2002). Nutrient Management. *Fertilizer News.* 47(8). 23-30, 33-40 and 43-49.

Tomar, N. K. (2000). Dynamics of Phosphorus in soils. *J. Indian Soc. Sci.* 48:4, 640-673.

Tomar, R.K.S. and Raghu, J.S. (1994) *Indian J. Pulses Res.* 7(1): 38-40.

Toor, A.S.; Bishnoi, S.R. and Singh, B. (1995). Effect of long-term application of phosphorus from poultry manure, farmyard manure and single super-phosphate on available nutrient status of soil. *Indian Soc. Soil Sci.: 60th Annual Convention,* Nov. 2-5, 119-120.

Tripathi, K.P. and Mishra, B. (2001). Kinetics of N Mineralization during Rice straw Decomposition in soils. *J. Indian Soc. Soil. Sci.* 49:1, 56-59.

Upadhyay, R.M.; Singh, B. and Katiyar, S.K. (1991). Effect of N, P and S application to block gram on yield and fate of P in an Inceptisol. *J. Indian Soc. Soil Sci.* 39:298-301.

Upadhyay, R.M.; Singh, B. and Katiyar, S.K. (1991). Effect of nitrogen, phosphorus and sulphur application to black gram on yield and fate of P in an Inceptisol. *J. Indian Soc. Soil Sci.* 39, 298-301.

Veena Sawhney, Amarjit and Singh, R. (1985) *Pl. Soil,* 86: 233-240.

Verma, A.K. and Subba Rao, N.S. (1972) Symp. *'Legume inoculants-Science and Technology',* New Delhi, October 23-25.

Verma, L.P.; Ram, P.C. and Maurya, B.R. (1988) *Ind. Chickpea News.* 18:31-33.

Verma, M.M. and Yadav, V.P. (2001). Effect of MRP and FYM in presence of rhizobium culture on chickpea (Cicer arietinum L.) var. K-850 in reducing soil pollution. *Proc. National Symp. on combating pollutants Accumulation in Ecosystem for Sustainable Agriculture.* 195-198.

Von Uexkull, H.R. & Mutert, E. (1992) Principles of balanced fertilization. In *Proc. Regional FADINAP Seminar on Fertilization and the Environment.* Chaing Mai, Thailand, 7-11 September, 1992.

Yadav, B.L. and Jakhar, S.R. (2001). Effect of tillage and P fertilizers on yield and water expense efficiency of rainfed mungbeam. *J. Indian Soc. Soil Sci.* 49:1, 193-194.

Yadav, B.S.; Patel, M.S. and Hadvani, G.J. (1991). Effect of FYM, P and Zn on groundnut in calcareous soil. *J. Indian Soc. Sci.,* 39:391-393.

Yadav, B.S.; Patel, M.S. and Hadvani, G.J. (1991). Effect of FYM; P and Zn on groundnut in calcareous soil. *J. Indian. Soc. Soil Sci.* 39:391- 393.

Yadav, D.S. (1990) *Legume Res.* 13(2): 65-68.

Yadav, K.S.; Suneja, S. and Sharma H.R. (1994) *Environ. Ecol.,* 12(4): 865-868.

Yadav, R.L.; Dwivedi, B.S.; Kamta Prasad; Tomar, O.K.; Shurpali, N.J.; Pandey, P.S. and Prasad, K. (2000). Yield trends and changes in soil organic-C and available-NPK in long rice - wheat system under integrated use of manures and fertilizers. *Field crop Research,* 68:3, 219-246.

Yadavanshi, H.S.; Kanwar, B.S. and Tripathi, B.R. (1984) *J. Indian Soc. Soil Sci.* 32, 97.